The Global Positioning System and GIS

An Introduction

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An Introduction

Second Edition

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Second Edition
Featuring hardware and GPS software from Trimble Navigation,
Limited, and GIS software from Environmental Systems Research
Institute (ESRI)

Michael Kennedy
University of Kentucky

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for

Alexander Kennedy

ABOUT THE AUTHOR

Michael Kennedy's involvement with Geographic Information Systems (GIS) began in the early 1970s with his participation on a task force formed by the Department of the Interior to provide technical recommendations for pending federal land use legislation.

In the mid-1970s he and coauthors wrote two short books on GIS, both published by the Urban Studies Center at the University of Louisville where he was enjoying sabbatical leave from the University of Kentucky. ***SpatialInformation Systems: An Introduction*** with Charles R.Meyers is a description of the components of a GIS and was a guide to building one at the time when there was no off-the-shelf software. ***Avoiding System Failure:Approaches to Integrity and Utility*** with Charles Guinn described potential pitfalls in the development of a GIS. With Mr. Meyers and R.Neil Sampson he also wrote the chapter *"Information Systems for Land Use Planning" for****Planning the Uses and Management of Land,*** a monograph published in 1979 by the American Society of Agronomy.

Professor Kennedy is also a computer textbook author, having cowritten, with Martin B.Solomon, ***Ten Statement Fortran Plus Fortran IV, Structured PL/ZERO Plus PL/ONE,*** and ***Program Development with TIPS andStandard Pascal,*** all published by Prentice-Hall.

Over the years Professor Kennedy has had a wide range of experiences relating computers and environmental matters. Primarily to be able to talk to planners about the newly emerging field of GIS he became certified as a planner by the American Institute of Certified Planners (AICP). He was Director of the Computer-Aided Design Laboratory at the University of Kentucky for several years. He has been invited to

teach GIS and/or programming at Simon Fraser University and several state or provincial universities: North Carolina, Florida, and British Columbia.

Outside of his interest in the Global Positioning System (GPS) the author's primary concern is in the development of computer data structures for the storage of geographic information. In work sponsored by the Ohio State University Center for Mapping and the Environmental Systems Research Institute, he is currently developing what he calls the dot-probability paradigm for the storage of spatial data. Fundamentally, the author is a programmer who has sought out the application of computers to environmental issues. He is currently an Associate Professor in the Geography Department at the University of Kentucky, where he teaches GIS and GPS.

CONTENTS

FOREWORD TO THE FIRST EDITION

Michael Kennedy's latest book brings together Geographic Information System (GIS) technology and Global Positioning System (GPS) technology with the aim of teaching how to couple them to effectively capture GPS data in the field and channel it to a GIS.

We at the Environmental Research Institute (ESRI) were especially pleased that he chose to use ESRI's GIS software (ArcInfo and ArcView) in writing his book, and we were happy to be able to provide him with some support in his efforts.

After 15 or 20 years in which very few textbooks were written about GIS and related technologies there is now a veritable flood of new GIS books coming into print. Why is this one especially valuable?

First, because it couples GPS/GIS in an especially intimate way. Michael's intention in writing was to make it possible for readers working alone or for students in a formal course to learn how to use GPS/GIS "hands on"; to walk away from this textbook ready to go into the field and start using Trimble Navigation's GeoExplorer and ESRI's ArcInfo and Arc View software to collect GPS field data and enter it into a GIS for immediate use.

Besides providing step-by-step instructions on how to do this, he provides appropriate background information in the form of theoretical discussions of the two technologies and examples of their use. He writes in an easy style, explaining the needed technical and scientific principles as he goes, and assuming little in the way of necessary prior instruction.

Instructors will find the text especially useful because Michael provides the kinds of detailed procedures and hints that help to make lab work "bullet proof" even for the inexperienced student. An accompanying CD-ROM has data which are likely to be useful in various ways to teacher and student alike.

Secondly, this book is important because GPS/GIS is such an extremely important technology! It is no exaggeration to say that GPS/GIS is ***revolutionizing*** aspects of many fields, including surveying (slashing the costs of many kinds of survey efforts and bringing surveying to parts of the world where surveys are non-existent, highly inaccurate, or long since outdated), the natural resource fields (providing rapid and far more accurate collection of field natural resource data of many kinds), and municipal planning (providing for the updating of all kinds of records based on accurate field checking), to name only a few. GPS is making practical the kinds of data collection which were simply out of the question only a few years ago because the necessary skilled teams of field personnel were unavailable and the costs of accurate field data collection were beyond the means of virtually all organizations which needed these kinds of data. GPS/GIS is changing all that. Use of the kinds of methods taught in ***The Global Positioning System and GIS*** is spreading very rapidly; GPS/GIS use will become commonplace throughout dozens of fields in just the next few years as costs of hardware and software continue to fall and books like this one increase the number of persons familiar with these two coupled technologies.

The impact of this revolution in data gathering will, I believe, have pro-found effects on the way in which we view the earth, on ways in which we exercise our stewardship of its resources for those who come after us, and on the professional practice of an extraordinary range of disciplines (engineering, oceanography, geology, urban planning, archaeology, agriculture, range management, environmental protection, and many, many others). I look forward to the time when ***tens of millions of people*** will make use of GPS/GIS technology every day, for thousands of purposes.

ESRI's aim as a company has always been to provide reliable and powerful GIS and related technologies to our clients and users and to help them use these technologies to make their work more effective and successful. By doing so, we hope to help make a difference in the world.

The ESRI authors' program was created to further those same goals. Michael Kennedy's ***The Global Positioning System and GIS*** is an extremely important part of that program and will, I believe, assist many persons to acquire and effectively use GPS/GIS in their work. In writing this book he has performed an important service, not just to his readers and the users of this

textbook, but to those whose lives will be improved because of the use of GPS/GIS technologies in the years ahead.

<div align="right">

Jack Dangermond
President, ESRI, Inc.

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FOREWORD TO THE SECOND EDITION

Michael Kennedy's timely revision of *The Global Positioning System and GIS* has occurred during a period of significant change in both GPS and GIS technologies. Firstly with GPS, the US Department of Defense has removed Selective Availability, the major source of error in GPS position and secondly "location", as an attribute, is becoming integrated into every day business process with the advent of Location Based Services.

In the first edition of his book, there are several predictions about the future used of GPS. Many of these have come true. Accuracy has improved, both gradually by improvements in the GPS receiver hardware and significantly by the removal of Selective Availability. Air Navigation is seeing transformation with the FAA's Wide Area Augmentation System (WAAS) being close to operational status. GPS is being used as a time base in most time critical applications such as the Internet and cellular telephone networks and we are seeing applications evolving which a few years ago had not been considered, for example the use of GPS to provide automatic guidance in agricultural applications, which in turn raises the productivity of scarce land resources.

Michael Kennedy also predicted that GPS in combination with other systems and technologies would provide positional information in places of poor or limited reception. This has certainly happened but it is the combination of reliable and accurate positioning, broadband wireless network technology and the Internet that is driving the need for a whole variety of additional types of spatial data that forms the underlying structure of Location Based Services. GIS is moving from a supporting, back room analysis tool to mission critical status as part of a 7×24 real time management tool. Combining the changes that have occurred in GPS to those that are occurring today in GIS with the addition of wireless networks and the Internet creates a

technology market space that is as exciting as the initial GPS/GIS market was when the first edition was written.

Trimble's new GeoExplorer 3 has been used for the updated examples in the text. This product typifies the improvements that have been made in GPS/GIS technology with improvements in the basic GPS technology but probably more importantly, improvements in the "ease of use" functions such as the user interface for feature and attribute collection. Functionality for the updating of spatial databases in addition to the primary function of data collection, are new in the GeoExplorer 3, highlighting the importance of maintaining existing data as the analysis based on the spatial data is only as accurate as the underlying data base.

As the use of GPS technology becomes more a part of our daily lives, from timing the Internet to proving position within mobile phones and location information for a range of location based services, the need for professionals skilled at collecting and maintaining spatial data bases can only increase. Michael Kennedy's second edition continues the theme of a clear step by step instruction on how to combine ESRI's software with Trimble's GeoExplorer to collect field data and transfer this to a GIS while understanding the theory behind the technologies.

Trimble is pleased to again be associated with Michael Kennedy's *TheGlobal Positioning System and GIS* and by providing this revision; he continues to provide the basis by which students of the text can gain a fundamental and practical understanding of how GPS/GIS can be applied in a vast range of applications.

Alan Townsend
Vice President
Mapping and GIS Division
Trimble Navigation Ltd

PREFACE FOR THE INSTRUCTOR[1]
Second Edition

The Second Edition—What's Different

- The major difference between this text and the first edition is the integration of many more examples of GIS data with the sample GPS data. The student gets to see GPS fixes superimposed on digital orthophotoquads, on topographic quadrangles digital raster graphic form, on soils and geologic coverages, on TIGER files, and so on. The primary lesson of the book—that the issues of datum, coordinate system, projection, and units are vital to correctly integrating GPS and GIS data— is reinforced.
- Data collection with both the Trimble GeoExplorer II and the GeoExplorer 3 is presented.
- There is more emphasis on Arc View, with the assumption that it will be the usual target of GPS conversion activities. The ability to convert GPS data to ArcInfo is still described—and, of course, one can convert shapefiles to coverages and vice versa.
- The effects and ramifications of the elimination of Selective Availability (SA) are an integral part of the text. The text reflects the tenfold improvement in unconnected GPS data created by the elimination of selective availability. It is pointed out that the results for corrected data haven't changed that much. And GIS almost always requires corrected data.
- The entire text has been combed through, carefully tested, and retested. Figures and photos have been added to make the exercises flow more smoothly.

Purpose and Audience

The purpose of this textbook/workbook, and the accompanying CD-ROM, is to provide a short, intermediate, or full term course in using the Global Positioning System (GPS) as a method of data

input to a Geographic Information System (GIS). The short course may either "stand alone" or be a two—to four-week segment in a general course in GIS. The text may either be used in a formal course with several students or as an individual self-teaching guide. There is the assumption that the students have at least a passing familiarity with GIS and with the most basic geographical concepts, such as latitude and longitude. But the book can serve as a gentle introduction to GPS even for those who do not intend to use the data in a GIS.

A Look at the Contents

First: A Note. If you have used the first edition of this text you will notice a number of enhancements and changes present in the new addition. I will point out the significant ones at the end of the discussion of each chapter below.

Chapter 1—Basic Concepts—is an introduction to GPS as a system. The field/lab work involves data collection with pencil and paper. This works best if the data collection point involves a surveyed-in monument, but it's not necessary. New: The Trimble GeoExplorer 3 is introduced and integrated into the text. Geo3 information is, however, kept separate from the Geo II text by the use of shaded boxes.

Chapter 2—Automated Data Collection—looks further into how GPS works. Project work includes taking GPS data and storing it in files, first in a receiver, then in a PC. You might want to have the students take data in the same place in Chapter 2 as in Chapter 1. New: GPS Pathfinder Office is the GPS software introduced, replacing Geo-PC and PFINDER.

Chapter 3—Examining GPS Data—first answers some questions to complete the discussion of the theory of GPS, and then gives the student, or other reader, experience with software for processing and displaying collected GPS data. GPS data sets are superimposed on digital orthophotoquads (DOQs)—including one showing a GPS track at the moment that Selective Availability was terminated—to show GPS data in context.

Chapter 4—Differential Correction—discusses the issue of accuracy and techniques for obtaining it. Practice first takes place with "canned" data— then with the user's own. New: Additional

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[1] Material for the student begins with the Introduction on page xxxi.

topics and exercises have been added, the effects of eliminating SA are discussed, and DOQs are used for illustration.

Chapter 5—Arc View, ArcData, and GPS—is a discussion of ESRI's Arc View product and an extensive exercise that is based on data from both GPS and the ArcUS A database. (In the previous edition this was Part 6. With the text's new emphasis on Arc View I felt it fit better before the chapter on GPS to GIS conversion.)

Chapter 6—Integrating GPS Data with GIS Data—has the reader putting GPS data into Arc View and/or ArcInfo. The issues of positional correctness are again addressed. New: This Chapter is a total overhaul of the first Edition's Part 5. Chapter 6 is mainly divided into two subchapters. In the first, the conversion process for Arc View (version 3.2) is given. The second does the same for ArcInfo (versions 7.2 and 8.1 workstation). I assume that most instructors will use one or the other, but not both.

Chapter 7—Beyond the Basics—discusses the highly important matters of (a) collecting feature attribute data as position data are obtained, and installing them automatically in a GIS, and (b) mission planning using Quick Plan. The Chapter also has sections on (c) navigating with GPS, and (d) real-time differential GPS. It provides hands-on exercises relating to each of these four topics.

Chapter 8—The Present and the Future—A brief discussion of the issues and uses of GPS today and some guesses about what is to come.

There are two appendixes: Appendix A gives additional sources for GPS information—mostly Internet pointers. Appendix B is a form for students to fill out when you assign exercises, lab practicals, and exams based on data contained on the CD-ROM. I do not include a glossary of GPS terms, but point to one on the Internet in Appendix A.

Approach: Both Theoretical and Hands-On

The approach I use is to divide each chapter into two modules:

- OVERVIEW
- STEP-BY-STEP

This division comes from my belief that learning a technical subject such as GPS involves two functions: education and training. The student must understand some of the theory and the language of the subject he or she is undertaking; but also, the

ability to perform tasks using the technology is likewise important, and such hands-on experience provides new insights into the subject. Many other books, on other technical subjects, attempt to perform both of these functions, but mix the functions together. It is my view— particularly in the case of GPS which involves several complex systems, fieldwork, and learning about hardware and software—that the two functions serve the learner best if they are distinctly separated. The theory is presented in the "Overview" module. It is laid out in a hierarchical, simple-to-complex, way (from the top, down). The training portion takes place in a linear (step-by-step) form: "do this; now do this."

There is heavy emphasis on getting the vital parameters—datum, projection, coordinate system, units—correct. No conscientious student should be able to leave a course based on this book and commit the all-too-easy sin of generating incorrect GIS information based on incorrectly converted GPS data.

Hardware and Software

Teaching the U.S. Global Positioning System (NAVSTAR) using GIS with a hands-on approach involves using particular hardware and software. I decided it was not possible to write a satisfactory text that was general with respect to the wide variety of products on the market. I therefore selected two of the most popular and capable products available: the Trimble Navigation GeoExplorer II and GeoExplorer 3 GPS receivers,[2] and Arc View and ArcInfo GIS software systems from Environmental Systems Research Institute (ESRI). If you choose to use other products—and there are several fine ones in both GPS and GIS—you may still use the text, but you will have to be somewhat creative in applying the STEP-BY-STEP sections.

An Instructor's Guide: On the CD-ROM

An instructor who undertakes to teach a GPS/GIS course for the first time may face a daunting task, as I know only too well. In addition to many of the problems that face those teaching combination lecture-and-lab courses, there are logistical problems created by the (assumed) scarcity of equipment, managing teams of students, the need to electrically charge the receiver batteries, the outdoor nature of some of the lab work, and other factors. I

have made an attempt to keep other teachers from encountering the difficulties I experienced, and to anticipate some others.

Please take a bit of time to investigate the CD-ROM. No special installation of the CD-ROM is required. All the files and folders may simply be copied to the location you desire using standard Windows procedures. To use the CD-ROM start by reading the file named **"READTHIS.1ST."** It is a simple text file that may be opened in any text editor (e.g., WORDPAD). This file will indicate how to access the "Instructor's Guide" and how to copy the demonstration data on the CD-ROM to the GPS2GIS folder of the root directory of any drive you wish on your machine.

The CD-ROM also contains other helpful sections. For example,

- digital copies of the paper forms in the text (such as latitude-longitude computations, equipment checkout and setup, base station information, and a form for exercises and exams) are provided so you may modify them for your situation and print them out for distribution to your students,
- outlines for courses of varying lengths and hands-on involvement levels,
- answers to questions and exercises posed in the text.

Demonstration Data: On the CD-ROM-ROM

The use of the text requires that some of the demonstration data on the CD-ROM be copied to a hard drive on your machine. The text is quite flexible with respect to use of data supplied on the CD-ROM in conjunction with the data the students, usually working in pairs, collect on their own. Most assignments begin with manipulating the canned data, to prevent surprises, followed by students using homegrown data, if time and interest permit.

In addition to the data for the exercises in the STEP-BY-STEP sections of the book, the CD-ROM contains a great number of files of GPS data from North America and, to a lesser extent, from other parts of the world. Some of these are within additional exercises, detailed on the CD-ROM, that may be used for student practice or student testing.

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[2] Also included on the CD-ROM are sections that will allow you to use this text with Trimble Navigation's Pathfinder Basic receivers.

The step-by-step procedures have been tested, and tested again, so the projects and exercises should work as indicated—subject, of course, to new releases of software, firmware, and hardware.

ACKNOWLEDGMENTS

Several companies for hardware, software, and support: ESRI for sponsoring the project and providing software; Trimble Navigation, for providing the GPS hardware; AST Research, for use of a pen computer for collecting data while traveling; and AccuPoint and OMNISTAR for access to their differential correction services.

John Bossler, of Ohio State University, who does really hi-tech GPS, and who was patient in letting me finish this text, delaying a project I was doing for him.

Hans Vinje, First Officer of the Nordic Empress, who took the time to explain the way ship navigators combine GPS with other navigational systems, and to Captain Ulf Svensson, who invited me to spend time on the bridge.

The folks at Ann Arbor Press, who did indeed "press" to get the book into final form: Skip DeWall and Sharon Ray. I should add that responsibil ity for the appearance of the text and any errors you may find rest entirely with the author. While I received considerable help in development of the material, I provided the camera-ready text and was responsible for the correctness and format of the final work.

My colleagues in the Department of Geography at UK—and particularly to Richard Ulack, its chair—who indulged my absences and absent-mindedness during the last weeks of this project.

And finally my dear friend Barb Emler, who repairs children's teeth from nine to five every day and justly believes that people ought to enjoy life without work outside of those times. She's right. And I will. For a while, anyway.

Further

In putting together the second edition, which for some reason was no less work than the first, I am very indebted to:

Dr. Thomas Meyer, Assistant Professor in the Department of Natural Resources Management and Engineering at the University of Connecticut, who used the text in his classes, and commented on several chapters of the text which kept me from making major mistakes in the area of geodesy.

Dr. Kenneth L.Russell, Professor at Houston Community College, who inflicted draft versions of the text on his students and carefully detailed the ways in which the text worked, and didn't

INTRODUCTION

Two of the most exciting and effective technical developments to emerge fully in the last decade are:

- the development and deployment of Global Positioning Systems (the GPS of the United States is called NAVSTAR), and
- the phenomenon of the Geographic Information System (GIS).

GIS is an extremely broad and complex field, concerned with the use of computers to input, store, retrieve, analyze, and display geographic information. Basically GIS programs make a computer think it's a map—a map with wonderful powers to process spatial information, and to tell its users about any part of the world, at almost any level of detail.

While GPS is also an extremely complex system, using it for navigation is simple by comparison. It allows you to know where you are by consulting a radio receiver. The accuracies range from as good as a few millimeters to somewhere around 15 meters, depending on equipment and procedures applied to the process of data collection.

More advanced GPS receivers can also record location data for transfer to computer memory, so GPS can not only tell you where you are—but also tell you where you were. Thus, GPS can serve as means of data input for GISs. This subject is not quite a simple as using GPS for navigation. Traditionally (if one can use that word for such a new and fast moving technology), GISs got their data from maps and aerial photos. These were either scanned by some automated means or, more usually, digitized manually using a handheld "puck" to trace map features—the map being placed on an electronic drafting board called a "digitizer." With GPS, the earth's surface becomes the digitizer board; the GPS receiver antenna becomes the puck. This approach inverts the entire

traditional process of GIS data collection: spatial data come directly from the environment and the map becomes a document of output rather than input.

A cautionary note: The aim of this text is to teach you to use GPS as a source of input to GIS. The book is somewhat unusual in that it has multiple characteristics: It is an informational discussion, a manual, and a workbook. What I try to do is present material in a way and in an order so you can gain both obvious and subtle knowledge from it if you are paying close attention. For each major subject there is an Overview followed by Step-by-Step procedures. After each step you should think about what the step implies and what you could learn from it. As with many tutorials, it may be possible, in the early parts of the text, to go through the steps sort of blindly, getting the proper results but not really understanding the lessons they teach. I advise against that.

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1
Basic Concepts

IN WHICH you are introduced to facts and concepts relatingto the NAVSTAR Global Positioning System and have yourfirst experience using a GPS receiver.

OVERVIEW

A sports club in Seattle decided to mount a hunting expedition. Theyemployed a guide who came well recommended, and whose own views of hisabilities were greater still. Unfortunately, after two days, the group was completely, totally lost. "You told me you were the best guide in the State ofWashington," fumed the person responsible for hiring the guide. "I am, Iam" claimed the man defensively. "But just now I think we're in Canada."

Stories like the one above should be told now (if at all), before they cease to be plausible. Actually, even at present, given the right equipment and a map of the general area, you could be led blindfolded to any spot in the great out-of-doors and determine exactly where you were. This happy capability is due to some ingenious electronics and a dozen billion dollars[1] spent by the U.S. government. I refer to NAVSTAR (NAVigation System with Time And Ranging; informally the "Navigation Star")—a constellation of from 24 to 32 satellites orbiting the Earth, broadcasting data that allows users on or near the Earth to determine their spatial positions. The more general term in the United States for such an entity is "Global Positioning System" or "GPS." The Russians have such a navigation system as well, which they call GLONASS (GLObal NAvigation Satellite System). (One might reflect that, for some purposes, the cold war lasted just long enough.) A more

general, recent acronym for such systems is GNSS, standing for Global Navigation Satellite Systems. In the western world, GPS usually implies NAVSTAR, so I will use the two designations interchangeably in this text.

Where Are You?

Geography, and Geographic Information Systems (GISs) particularly, depend on the concept of location. Working with "location" seems to imply that we must organize and index space. How do we do that?

Formally, we usually delineate geographical space in two dimensions on the Earth's surface with the latitude-longitude graticule, or with some other system based on that graticule.

But informally, and in the vast majority of instances, we organize space in terms of the features in that space. We find a given feature or area based on our knowledge of other features—whether we are driving to Vancouver or walking to the refrigerator. Even planes and ships using radio navigational devices determine their positions relative to the locations of fixed antennae (though some of the radio signals may be converted to graticule coordinates).

Unlike keeping track of time, which was initially computed relative to a single, space-based object (the sun), humans kept track of space—found their way on the ground—by observing what was around them.

Another, somewhat parallel way of looking at this issue is in terms of absolute versus relative coordinates. If I tell you that Lexington, Kentucky is at 38 degrees (38°) north latitude, 84.5° west longitude, I am providing you with absolute coordinates. If I say, rather, that Lexington is 75 miles south of Cincinnati, Ohio and 70 miles east of Louisville, Kentucky, I have given you relative coordinates.

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[1] On the other hand, as you will see soon, we get a lot for this $12 billion. As this book goes to press the U.S. government is considering spending ten times that much for an antiballistic missile system (ABM) which is highly unlikely to be able to stop a missile attack, and guaranteed not to stop an attack that comes by truck, small boat, or other conveyance. In other words, although GPS was expensive it does have the advantage of working—something that ABM will not do.

Relative coordinates usually appeal more to our intuitive comprehension of "location" than do absolute coordinates; however, relative coordinates can be quite precise.

To pass spatial information around, humans developed maps to depict mountains and roads, cities and plains, radio stations and sinkholes. Maps aid both the formal and informal approaches that humans use to find objects and paths. Some maps have formal coordinates, but maps without graticule markings are common. All maps appeal to our intuitive sense of spatial relationships. The cartographer usually relies on our ability to use the "cognitive coordinates" in our memory, and our abilities to analyze, to extrapolate, and to "pattern match" the features on the map. It is good that this method works, since, unlike some amazing bird and butterfly species, humans have no demonstrated sense of an absolute coordinate system. But with maps, and another technological innovation, the magnetic compass, we have made considerable progress in locating ourselves.

I do not want to imply that absolute coordinates have not played a significant part in our position-finding activities. They have, particularly in navigation. At sea, or flying over unlit bodies of land at night, captains and pilots used methods that provided absolute coordinates. One's position, within a few miles, can be found by "shooting the stars" for a short time with devices such as sextants or octants. So the GPS concept—finding an earthly position from bodies in space—is not an entirely new idea. But the ability to do so during the day, almost regardless of weather, with high accuracy and almost instantaneously, makes a major qualitative difference. As a parallel, consider that a human can move by foot or by jet plane. They are both methods of locomotion, but there the similarity ends.

GPS, then, gives people an easy method for both assigning and using absolute coordinates. Now, humans can know their **positions** (i.e., the coordinates that specify where they are); combined with map and/or GIS data they can know their **locations** (i.e., where they are with respect to objects around them). I hope that, by the time you've completed this text and experimented with a GPS receiver, you will agree that NAVSTAR constitutes an astounding leap forward.

WHAT TIME IS IT?

While this is a text on how to use GPS in GIS—and hence is primarily concerned with positional issues, it would not be complete without mentioning what may, for the average person, be the most important facet of GPS: providing Earth with a universal, exceedingly accurate time source. Allowing any person or piece of equipment to know the exact time has tremendous implications for things we depend on every day (like getting information across the Internet, like synchronizing the electric power grid and the telephone network). Further, human knowledge is enhanced by research projects that depend on knowing the exact time in different parts of the world. For example, it is now possible to track seismic waves created by earthquakes, from one side of the earth, through its center, to the other side, since the **exact** time[2] may be known worldwide.[3]

GPS AND GIS

The subject of this book is the use of GPS as a method of collecting locational data for Geographic Information Systems (GIS). The appropriateness of this seems obvious, but let's explore some of the main reasons for making GPS a primary source of data for GIS:

- Availability: In 1995, the U.S. Department of Defense (DoD) declared NAVSTAR to have "final operational capability." Deciphered, this means that the DoD has committed itself to maintaining NAVSTAR's capability for civilians at a level specified by law, for the foreseeable future, at least in times of peace. Therefore, those with GPS receivers may locate their positions anywhere on the Earth.
- Accuracy: GPS allows the user to know position information with remarkable accuracy. A receiver operating by itself, can let you locate yourself within 10 to 20 meters of the true

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[2] Well, right, there is no such thing as "exact" time. Time is continuous stuff like position and speed and water, not discrete stuff like people, eggs, and integers, so when I say exact here I mean within a variation of a few billionths of a second—a few nanoseconds.

[3] The baseball catcher Yogi Berra was once asked "Hey Yogi, what time is it?", to which Berra is said to have replied, "You mean right now?" Yes, Yogi, **RIGHT NOW!**

position. (And later you will learn how to get accuracies of 2 to 5 meters.) At least two factors promote such accuracy:

First, with GPS, we work with primary data sources. Consider one alternative to using GPS to generate spatial data: the digitizer. A digitizer is essentially an electronic drawing table, wherewith an operator traces lines or enters points by "pointing"—with "crosshairs" embedded in a clear plastic "puck"—at features on a map.

One could consider that the ground-based portion of a GPS system and a digitizer are analogous: the Earth's surface is the digitizing table, and the GPS receiver antenna plays the part of the cross-hairs, tracing along, for example, a road. But data generation with GPS takes place by recording the position on the most fundamental entity available: the Earth itself, rather than a map or photograph of a part of the Earth that was derived through a process involving perhaps several transformations.

Secondly, GPS itself has high inherent accuracy. The precision of a digitizer may be 0.1 millimeters (mm). On a map of scale 1:24,000, this translates into 2.4 meters (m) on the ground. A distance of 2.4 m is comparable to the accuracy one might expect of the properly corrected data from a medium-quality GPS receiver. It would be hard to get this out of the digitizing process. A secondary road on our map might be represented by a line five times as wide as the precision of the digitizer (0.5 mm wide), giving a distance on the ground of 12 m, or about 40 feet.

On larger-scale maps, of course, the precision one might obtain from a digitizer can exceed that obtained from the sort of GPS receiver commonly used to put data into a GIS. On a "200 scale map" (where one inch is equivalent to 200 feet on the ground) 0.1 mm would imply a distance of approximately a quarter of a meter, or less than a foot. While this distance is well within the range of GPS capability, the equipment to obtain such accuracy is expensive and is usually used for surveying, rather than for general GIS spatial analysis and mapmaking activities. In summary, if you are willing to pay for it, at the extremes of accuracy, GPS wins over all other methods. Surveyors know that GPS can provide horizontal, real-world accuracies of less than one centimeter.

- Ease of use: Anyone who can read coordinates and find the corresponding position on a map can use a GPS receiver. A

single position so derived is usually accurate to within 10 meters or so. Those who want to collect data accurate enough for a GIS must involve themselves in more complex procedures, but the task is no more difficult than many GIS operations.

- GPS data are inherently three-dimensional: In addition to providing latitude-longitude (or other "horizontal" information), a GPS receiver may also provide altitude information. In fact, unless it does provide altitude information itself, it must be told its altitude in order to know where it is in a horizontal plane. The accuracy of the third dimension of GPS data is not as great, usually, as the horizontal accuracies. As a rule of thumb, variances in the horizontal accuracy should be multiplied by 1.5 (and perhaps as much as 3.0) to get an estimate of the vertical accuracy.

ANATOMY OF THE TERM: "GLOBAL POSITIONING SYSTEM"

Global: anywhere on Earth. Well, almost anywhere, but not (or not as well):

- inside buildings
- underground
- in very severe precipitation
- under heavy tree canopy
- around strong radio transmissions
- in "urban canyons" amongst tall buildings
- near powerful radio transmitter antennas

or anywhere else not having a direct view of a substantial portion of the sky. The radio waves that GPS satellites transmit have very short lengths—about 20 cm. A wave of this length is good for measuring because it follows a very straight path, unlike its longer cousins such as AM and FM band radio waves that may bend considerably. Unfortunately, shortwaves also do not penetrate matter very well, so the transmitter and the receiver must not have much solid matter between them, or the waves are blocked, as light waves are easily blocked.

Positioning: answering brand-new and age-old human questions. Where are you? How fast are you moving and in what direction? In what direction should you go to get to some other

specific location, and how long would it take at your speed to get there? **And, most importantly for GIS, wherehave you been?**

System: a collection of components with connections (links) among them. Components and links have characteristics. GPS might be divided up in the following way:[4]

The Earth

The first major component of GPS is Earth itself: its mass and its surface, and the space immediately above. The mass of the Earth holds the satellites in orbit. From the point of view of physics, each satellite is trying to fly by the Earth at four kilometers per second. The Earth's gravity pulls on the satellite vertically so it falls. The trajectory of its fall is a track that is parallel to the curve of the Earth's surface.

The surface of the Earth is studded with little **"monuments"—** carefully positioned metal or stone markers—whose coordinates are known quite accurately. These lie in the "numerical **graticule**" which we all agree forms the basis for geographic position. Measurements in the units of the graticule, and based on the positions of the monuments, allow us to determine the position of any object we choose on the surface of the Earth.

Earth-Circling Satellites

The United States GPS design calls for a total of at least 24 and up to 32 solar-powered radio transmitters, forming a constellation such that several are "visible" from any point on Earth at any given time. The first one was launched on February 22, 1978. In mid-1994 all 24 were broadcasting. The minimum "constellation" of 24 includes three "spares." As many as 28 have been up and working at one time.

The newest GPS satellites (designated as Block IIR) are at a "middle altitude" of about 11,000 nautical miles (nm), or roughly 20,400 kilometers (km) or 12,700 statute miles above the Earth's surface. This puts them above the standard orbital height of the space shuttle, most other satellites, and the enormous amount of

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[4] Officially, the GPS system is divided up into a Space Segment, a Control Segment, and a User Segment. We will look at it a little differently. One of the many places to see official terminology, at the time this book went to press, is http://tycho.usno.navy.mil/ gpsinfo.html#seg.

space junk that has accumulated. They are also well above Earth's air, where they are safe from the effects of atmospheric drag. When GPS satellites "die" they are sent to orbits about 600 miles further out.

GPS satellites are below the geostationary satellites, usually used for communications and sending TV, telephone, and other signals back to Earth-based fixed antennas. These satellites are 35, 763 km (or 19,299 nm or 22,223 sm) above the Earth, where they hang over the equator relaying signals from and to ground-based stations.

The NAVSTAR satellites are neither polar nor equatorial, but slice the Earth's latitudes at about 55°, executing a single revolution every 12 hours. Further, although each satellite is in a 12 hour orbit, an observer on Earth will see it rise and set about 4 minutes earlier each day.[5] There are four or five satellites in slots in each of six distinct orbital planes (labeled A, B, C, D, E, and F) set 60 degrees apart. The orbits are almost exactly circular.

The combination of the Earth's rotational speed and the satellites' orbits produces a wide variety of tracks across the Earth's surface. Figure 1–1 is a view of the tracks which occurred during the first two hours after noon on St. Patrick's Day, 1996. You are looking down on the Earth, directly at the equator and at a (north-south) meridian that passes through Lexington, Kentucky. As you can see, by Figure 1–1, the tracks near the equator tend to be almost north-south. The number of each satellite is shown near its track; the number marks the point where the satellite is at the end of the two-hour period.

GPS satellites move at a speed of 3.87 km/sec (8,653 miles per hour). The Block IIR satellites weigh about 1077 kilograms (somewhat more than a ton) and have a length of about 11.6 meters (about 38 feet) with the solar panels extended. Those panels generate about 1100 watts of power. The radio on board broadcasts with about 40 watts of power. (Compare that with your "clear channel" FM station with 50,000 watts.) The radio frequency used for the civilian GPS signal is called "GPS L1" and is at 1575. 42 megaHertz (MHz). Space buffs might want to know that they usually get into orbit on top of Boeing Delta II rockets fired from the Kennedy Space-flight Center at Cape Canaveral in Florida.

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[5] Why? Answers to several questions that may occur to you will be supplied in Chapters 2 and 3. We avoid the digression here.
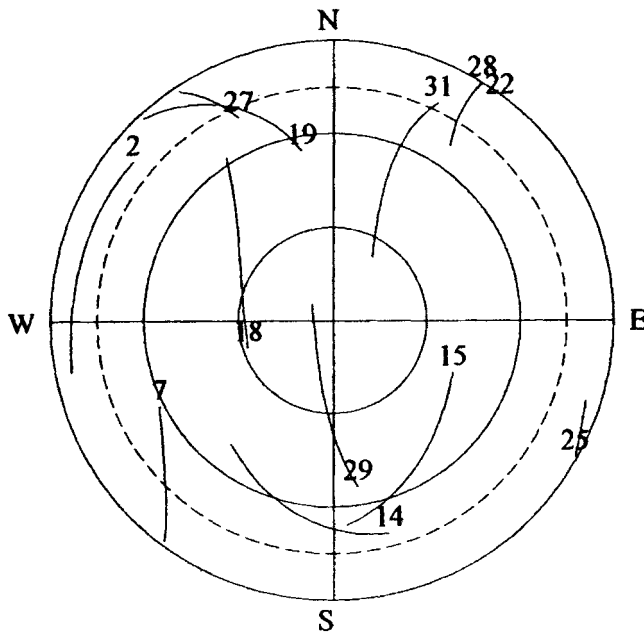
Figure 1–1. GPS satellite tracks looking from space toward the Equator.

Each satellite has on board four atomic clocks (either cesium or rubidium) that keep time to within a billionth of a second or so, allowing users on the ground to determine the current time to within about 40 billionths of a second. Each satellite is worth about $65 million and has a design life of 10 years. Figure 1–2 shows an image of a NAVSTAR satellite.

Ground-Based Stations

While the GPS satellites are free from drag by the atmosphere, their tracks are influenced by the gravitational effects of the moon and sun, and by the solar wind. Further, they are crammed with electronics. Thus, both their tracks and their innards require monitoring. This is accomplished by four ground-based stations near the equator, located on Ascension Island in the South Atlantic, at Diego Garcia in the Indian Ocean, and on Kwajalein Atoll, and in Hawaii, both in the Pacific, plus the master control station (MCS) at Schriever (formerly Falcon) Air Force Base near Colorado Springs, Colorado. A sixth station is planned to begin operation at Cape Canaveral, Florida. Each satellite passes over at least one monitoring station twice a day. Information developed by
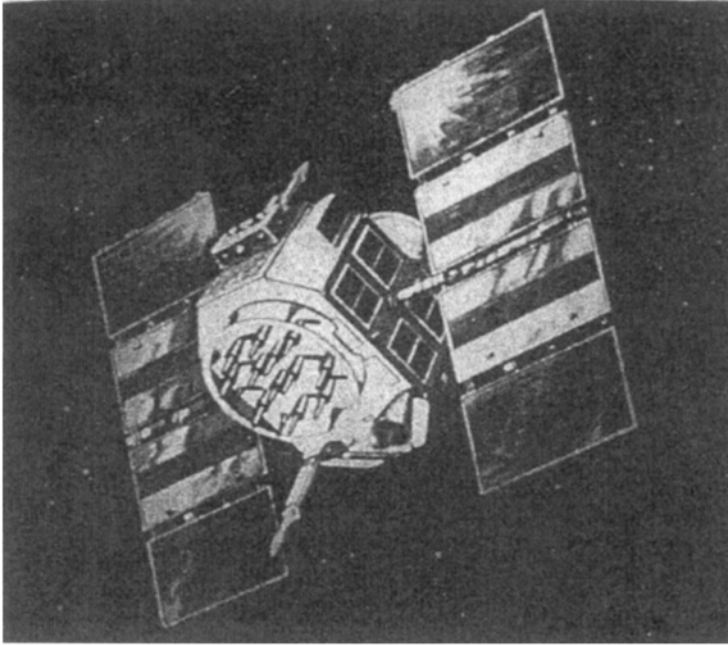
Figure 1–2. A NAVSTAR GPS satellite.

the monitoring station is transmitted back to the satellite, which in turn rebroadcasts it to GPS receivers. Subjects of a satellite's broadcast are the health of the satellite's electronics, how the track of the satellite varies from what is expected, the current **almanac**[6] for all the satellites, and other, more esoteric subjects which need not concern us at this point. Other ground-based stations exist, primarily for uploading information to the satellites.

Receivers

This is the part of the system with which you will become most familiar. In its most basic form, the satellite receiver consists of

- an antenna (whose position the receiver reports),
- electronics to receive the satellite signals,
- a microcomputer to process the data that determines the antenna position, and to record position values,

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[6] An almanac is a description of the predicted positions of heavenly bodies.

- controls to provide user input to the receiver, and
- a screen to display information.

More elaborate units have computer memory to store position data points and the velocity of the antenna. This information may be uploaded into a personal computer or workstation, and then installed in GIS software database. Another elaboration on the basic GPS unit is the ability to receive data from and transmit data to other GPS receivers—a technique called "realtime differential GPS" that may be used to considerably increase the accuracy of position finding.

Receiver Manufacturers

In addition to being an engineering marvel and of great benefit to many concerned with spatial issues as complex as national defense or as mundane as refinding a great fishing spot, GPS is also big business. Dozens of GPS receiver builders exist—from those who manufacture just the GPS "engine," to those who provide a complete unit for the end user. In this text we explain the concepts in general, but use Trimble Navigation, Ltd. equipment since it works well, is quite accurate, has a program of educational discounts, and is likely to be part of educational GPS labs throughout the country.

The United States Department of Defense

The U.S. DoD is charged by law with developing and maintaining NAVSTAR. It was, at first, secret. Five years elapsed from the first satellite launch in 1978 until news of GPS came out in 1983. The story, perhaps apocryphal, is that President Reagan, at the time a Korean airliner strayed into Soviet air space and was shot down, lamented something like "this wouldn't have happened if the damn GPS had been up." A reporter who overheard wanted to know what GPS was. In the almost two decades since—despite the fact that parts of the system remain highly classified—mere citizens have been cashing in on what Trimble Navigation, Ltd. calls "The Next Utility."

There is little question that the design of GPS would have been different had it been a civilian system "from the ground up." But then, GPS might not have been developed at all. Many issues must be resolved in the coming years. A Presidential Directive issued in

March of 1996 designated the U.S. Department of Transportation as the lead civilian agency to work with DoD so that nonmilitary uses can bloom. DoD is learning to play nicely with the civilian world. They and we all hope, of course, that the civil uses of GPS will vastly outpace the military need.

One important matter has been addressed: For years the military deliberately corrupted the GPS signals so that a single GPS unit, operating by itself (i.e., **autonomously**), could not assure accuracy of better than 100 meters. This policy (known as Selective Availability [SA]) was terminated on 2 May 2000. Now users of autonomous receivers may know their locations within 10 to 20 meters.

Users

Finally, of course, the most important component of the system is **you:** the **"youser,"** as my eight-year-old spelled it. A large and quickly growing population, users come with a wide variety of needs, applications, and ideas. From tracking ice floes near Alaska to digitizing highways in Ohio. From rescuing sailors to pinpointing toxic dump sites. From urban planning to forest management. From improving crop yields to laying pipelines. Welcome to the exciting world of GPS!

HOW WE KNOW WHERE SOMETHING IS

First, a disclaimer: This text does not pretend to cover issues such as geodetic datums, projections, coordinate systems, and other terms from the fields of geodesy and surveying. In fact, I am going to make it a point not even to define most of these terms, because simply knowing the definitions will not serve you unless you do a good bit of study. Many textbooks and web pages are available for your perusal. These fields, concepts, and principles may or may not be important in the collection of GPS information for your GIS use —depending on the sort of project you undertake. What is important, vital in fact, is that when GPS data are to be combined with existing GIS or map information, the datum designation, the projection designation, the coordinate system designation, and the measurement units that are used must be identical.

Before we undertake to use a GPS receiver to determine a **position,** it is important to understand what is meant by that term. It seems like a straightforward idea, but it has confused a lot

of people, particularly when a given position is described as a set of numbers.[7]

Take a tent stake, or a knitting needle, or a table knife and stick it vertically into a patch of ground. Now reflect upon the fact that the object is not moving with respect to the planet,[8] as it would be if you stuck it into the soil in a flowerpot on the deck of a ship. The location of the object may be identified through time by three unchanging numbers of latitude, longitude, and altitude. In other words, it is where it is. But in the last century, teams of mathematicians and scientists (skilled in geodesy) have developed other sets of numbers to describe exactly the same spot where your object now resides. **The spot's position doesn't change, but the description of it does.**

Ignoring the matter of altitude for the moment, suppose you put your object into the ground at latitude 38.0000000° (North) and longitude 84.5000000° (West), according to the latest belief about where the center of the earth is and where its poles are. This most recent, widely-accepted view is the datum described as the World Geodetic System of 1984 (WGS84), based on the GRS80 ellipsoid.[9] In the coterminous states of the United States, this datum is said to be virtually identical (within millimeters) with the North American Datum of **1983** (NAD**83**). As I indicated, if you want to know more there are plenty of sources.

Prior to this latest determination of the latitude-longitude graticule, many people and organizations in the United States used the North American Datum of **1927** (NAD**27**) as the best estimate of where the latitude-longitude graticule was positioned, based on parameters determined by Clarke in 1866. According to this datum, your object would be at latitude 37.99992208° and longitude 84.50006169°. This looks like an insignificant difference but translates into about 10 meters on the earth's surface. To consider another way of thinking about what this means: If you put a second object in the ground at 38° latitude and 84.5° according to NAD27, it would be 10 meters away from the first one. Does that sound like a lot? People have been shot in disputes over much smaller distances. So, when a GPS receiver gives you a latitude and longitude you must know the datum that is the basis for the numbers. There are hundreds of datums—almost every

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[7] Descriptions of points aren't always numbers. A possibly apocryphal "meets & bounds" description a couple of centuries ago of a point in Kentucky was "two tomahawk throws from the double oak in a northerly direction."

country has its own. NAVSTAR GPS is based fundamentally on WGS84 but lots of GPS units, including the ones you will be using, can calculate and display coordinates in many other datums.

There are many reasons why people do not find it convenient to use latitude and longitude to describe a given point, or set of points, on the earth's surface. One is that doing calculations using latitude and longitude—say, determining the distance between two points—is a pretty complex matter involving such things as products of sines and cosines. For a similar distance calculation, if the points are on a Cartesian plane, the worst arithmetic hurdle is a square root.

Another reason not to use latitude and longitude measures for many applications is that it doesn't work well for several aspects of mapmaking. Suppose you plot many points on the Earth's surface —say the coastline of a small island some distance from the equator—on a piece of ordinary graph paper, using the longitude numbers for "x" coordinates and latitude numbers for "y" coordinates. The shape of the island might look pretty strange compared with how it would appear if you got up in an airplane and looked down on it. And if you measured distances or angles or areas on the plot you would not get useful numbers. This is due to a characteristic of the spherical coordinate system: The length of an arc of a degree of longitude does not equal the length of an arc of a degree of latitude. It comes close to equal near the equator but it is nowhere near close as you go further north or south from the equator. At the equator a degree of longitude is about 69.17 miles. Very near the north pole a degree of longitude might be 69.17 inches. (A degree of latitude, on the other hand, varies only between about 68.71 miles near the equator and 69.40 miles near the poles.)

A good solution to these problems (calculation and plotting) for relatively small areas is the concept of a "projection" with which you are no doubt familiar. The term comes from imagining a process in which you place a light source within a transparent globe

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[8] Well, it's not moving much. If you are in Hawaii it is moving northwest at about four inches per year. If you are unfortunate enough to do this exercise when there is an earthquake happening it might be moving quite a bit, and it might not return to its original position.

[9] GRS80 is a global geocentric system based on the ellipsoid adopted by the International Union of Geodesy and Geophysics (IUGG) in 1979. GRS80 is the acronym for the Geodetic Reference System 1980.

that has features inscribed on it, and let the light fall on a flat piece of paper (or one that is curved in only one direction and may be unrolled to become flat).[10] The shadows of the features (say, lines or areas) will appear on the paper. You can then apply a Cartesian coordinate system to the paper, which gives you the advantages of easy calculation and more realistic plotting. However, distortions are inherent in any projection process; most of the points on the map will not correspond exactly to their counterparts on the ground. The degree of distortion is greater on maps that display more area.

In summary, latitude and longitude numbers of a given datum provide an exact method of referencing any given single point, but they are difficult to calculate with, and multiple points suffer from distortion problems when plotted. Projected coordinate numbers are easy to calculate with but, in general, misplace points with respect to other points—thus producing errors in the distances, sizes, shapes, and directions.

Let's look at some common representations of the position of our object.

A coordinate system called Universal Transverse Mercator (UTM) was developed based on a series of 60 transverse Mercator projections. These projections are further subdivided into areas, called **"zones,"** covering 6° of longitude and, usually, 8° of latitude. A coordinate system is imposed on the resulting projection such that the numbers are always positive, and increasing "to the right and up."

The representation of our object (at 38°N and 84.5°) in the UTM coordinate system, when that system is based on WGS84, is a **"northing"** of 4,208,764.4636 meters and an **"easting"** of 719,510.3358 meters. The northing is the distance along the surface of a "bumpless" earth, in meters, from the equator. The easting is somewhat more complicated to explain since it depends on the zone and a coordinate system that allows the number to always be positive. Consult a textbook on geodesy, cartography, or look at some of the ten thousand plus web pages that come up when you type "UTM coordinate system transverse Metcator" into an Internet search engine (e.g., www.google.com).

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[10] This is a sort of a cartoon of what a map projection is. A map projection is actually a mathematical transformation that "maps" points on the globe to points on a plane; depending on the projection, the process is quite complex; a single light source at the center of the globe does not suffice to explain it.

However, there is also a version of the UTM coordinate system based on NAD27. In this case, our object would have different coordinates: northing 4,208,550.0688 and easting 719,510.6393, which makes for a difference of about 214 meters. If you compare these coordinates with the previous UTM coordinates you see that virtually all of the difference is in the north-south direction. (While this is true for this particular position, it is not true in general.) Obviously if you tried to combine WGS84 UTM data with NAD27 UTM data the locations they depict would not match.

All states in the United States have State Plane Coordinate Systems (SPCSs) developed by the U.S. Coast and Geodetic Survey, originally in the 1930s. These systems—sometimes two or more are required for a given state—are based on different projections (mostly, transverse Mercator or another called Lambert Conformal Conic) depending on whether the state is mostly north-south (like California) or mostly east-west (Tennessee). The units are either feet or meters. Zone boundaries frequently follow county boundaries. As you can infer, each state operates pretty independently and the coordinate system(s) used in one state are not applicable in its neighbors. In Kentucky 38.0000000° (North) and longitude 84.5000000° (West) would translate into a northing of 1,568,376.1900 feet and an easting of 182,178.3166 feet when based on WGS84. However, when the basis is NAD27, the coordinates are 1,927,939.8692 and 182,145.9821, which makes a difference of some 68 miles!

Why the large differences in coordinate systems based on NAD27 versus those based on WGS84? Because those responsible for the accuracy of other coordinate systems took good advantage of the development of WGS84—a worldwide, earth-centered, latitude-longitude system—to make corrections or improvements to those other systems.

State plane coordinate systems have a scale error maximum of about 1 unit in 10,000. Suppose you calculated the Cartesian distance (using the Pythagorean theorem) between two points represented in a state plane coordinate system to be exactly 10,000 meters. Then, with a perfect tape measure pulled tightly across an idealized planet, you would be assured that the measured result would differ by no more than one meter from the calculated one. The possible scale error with the UTM coordinate system may be larger: 1 in 2,500.

STEP-BY-STEP

Disclaimer

The Step-by-Step sections of this book depend on hardware, firmware, and software created by various manufacturers. As you know, such entities may change over time, slightly or radically, as bugs are found, improvements are made, or for other reasons. All the Step-by-Step procedures were checked out in the early months of 2001 and found to work. The disclaimer is: there is no guarantee that they will work for you exactly as intended. You may have to be flexible and look for work-arounds or find different menu items. The Help files may help; they may not. But, anyway, you wouldn't be trying to use computers if you weren't flexible, would you?

Preparation

For the Step-by-Step part of this chapter you should obtain a topo map (United States Geological Survey [USGS] topographic quadrangle), if you are in the United States, of the area in which you are planning to collect data. This map will also indicate the Universal Transverse Mercator (UTM) zone (e.g., 16T), which you should write down for use in PROJECT 1C.

Also, see if you can find a nearby survey marker with known coordinates. (A web site listing all U.S. Coast and Geodetic Survey markers may be found at www.ngs.noaa.gov.[11] Click on the hyperlink that invites you to get the data sheets related to "Find a point.")

PROJECT 1A

Getting Acquainted with a GPS Receiver

You begin your first Global Positioning System project by becoming acquainted with a typical GPS receiver, while still inside a building. Your investigation begins with a GeoExplorer[12] receiver, and a notebook.

The GeoExplorer and the enhanced version, the GeoExplorer II, operate in much the same fashion, so I will simply use the name GeoExplorer to refer to both units.

The primary external difference is that the "II" has a receptacle that allows use of an external antenna. The original receiver was

built with only an internal antenna, making it less convenient in some situations—as inside an automobile, for instance.

The notebook—with paper and a sturdy writing surface—is there partly to get you used to the idea that a GPS receiver and a note-taking ability must go hand in hand. After this first project, most of the data you take will be recorded in computer files, but some will not and must be written down. The notebook will also provide an index to the computer files you record.

> You may be using a GeoExplorerS (called Geo3 in this text to differentiate it from GeoExplorers I and II), which is a much different device in terms of how it is operated, but which produces the same results. The Geo3 comes with a CD-ROM that contains a tutorial that describes in detail how to use it so I will not do so in this text. Instead I will assume you have some knowledge of the Geo3 from going through the tutorial on the CD-ROM. However, I will give summary instructions for use of the Geo3 in boxes such as this so you can do the same projects as with the standard GeoExplorer.

> If you are using the Geo3 you should first read the instructions herein for the GeoExplorer and then adapt them for the Geo3, with guidance from these boxes.

A GeoExplorer receiver, with its built-in antenna, is a handheld device about 3.75 wide by 7 long and less than 2 thick, and weighs less than a pound. It is usually powered in the field by a standard VideoCam battery that weighs about 1.5 pounds. Alternative power sources are "AA" batteries and the auxiliary power (cigarette lighter) receptacles in a car, boat, or airplane.

While the unit is very complex internally, containing not only signal reception electronics, but a microcomputer with a quarter megabyte memory as well, its user controls are quite basic: eight buttons. See Figure 1–3.

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[11]www.ngs.noaa.gov takes you to the web site of the National Geodetic Survey, which is part of the National Oceanic and Atmospheric Administration.

[12] The GeoExplorer is manufactured by Trimble Navigation, Ltd., of Sunnyvale, California.

Figure 1–3. The GeoExplorer II GPS receiver from Trimble Navigation.

> The Geo3 contains its own batteries. While an external power kit is available, the internal batteries last for many hours and are probably sufficient for most fieldwork. Since it contains its own batteries it is also heavier. See Figure 1–4.
> The Geo3 contains a megabyte of memory. It is a somewhat larger unit with a much bigger screen.

The button that is "furthest south" is the on-off control. The "up" and "down" buttons scroll through the lines of text and numbers of whatever screen is currently displayed. The "left" and "right" buttons move a cursor from character to character within a string of characters and perform other selection functions. The center button—the one with the diamond—is the **"Command"** key which sets options chosen by the others. We will designate this key as **"CMD"** from now on.

Visual output to the user is provided by a four-line, 16 character per line LCD display. In many instances the screen serves as a window to a list of more than four lines, but the user can see all of them by repeatedly pressing the "down" key (or the "up" key).
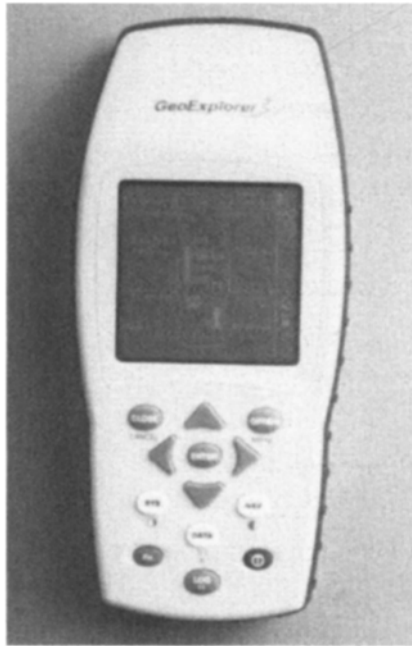
Figure 1–4. The Geo3 GPS receiver from Trimble Navigation.

Power On and Off

{__}[13]

{__} Find the cord with the small cylindrical jack on one end and the large cylinder on the other. Connect it to the receiver and the battery (or battery charger). A small green light at the base of the receiver should glow. The screen of the receiver may be blank, or may display characters. If you see characters, hold down the on-off button until the display becomes blank.

{__} Press the on-off button. Some preliminary screens will appear that describe the receiver type, firmware version, and other facts. Note these items in your notebook. (If you don't get all of them this time, check the next time you turn the unit on.)

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[13] The designation "{__}" indicates that some action is required on your part. Perhaps you will want to check off each activity as it is performed. A sentence in italics following {__} indicates a general activity that is to occur; that activity is further explained by succeeding statements.

Main Menu
1.Data Capture
2.Position
3.GPS Status
4.Navigation
5.Date & Time
6.Configuration
7.Data Transfer

> To turn on the Geo3 simply press the "power on" button—lower righthand corner.

{__} What you see now depends on the state the receiver was left in by the previous user. Your goal at this point is to return to the Main Menu. Press "Esc" until it appears. Here, for example and for future reference, is the Main Menu.

{__} Press and hold the on-off button. The receiver will not immediately go off. Rather, a screen will appear that tells you that "OFF" is impending in 5, 4, 3, etc. seconds. This "delayed off" serves a purpose. In case you are recording data and accidentally attempt to switch the receiver off, you get a chance to recover from this error by simply releasing the button. (If, while the screen is counting down, you press "CMD," the receiver goes off immediately. Practice that now.)

{__} Turn the receiver on again. Now turn it off and disconnect the power cord at the "cigarette lighter" junction. **You should do thisevery time you turn the receiver off unless you plan to use it againwithin a quarter of an hour.** The receiver takes power from the battery even though it is off. You knew that anyway, didn't you? That little green light at the base of the receiver won't glow all on its own.

{__} Reconnect the power cord and turn the receiver on again. Darken the room or move to a relatively dark place. Hold the on-off switch down and press the key with the bent arrow on it. Note that this causes a screen **"backlight"** to come on. Repeat the process to turn the backlight off. Be aware that, if you are using battery power, the backlight reduces the amount of time you can use the unit without recharging the battery pack.

{__} With the receiver on, press and hold the on-off key and the "up" key together. Note the change in contrast on the screen.

Release both keys. Now try the same with the "down" key. You can make the screen more readable by adjusting the contrast, depending on the lighting conditions around you. (This contrast-adjustment process may also turn on the backlight, so be careful not to leave the backlight on and drain the battery.) Turn the receiver off.

{__} Now cycle through this on-off procedure a couple of times, employing the backlight also, until you get comfortable with it (and have noted down the information on the initial screens).

On the Geo3 the backlight is set by first pressing (or pressing and holding down) the blue Fn button (which tells the receiver to shift into a different function mode), and pressing the button over the lightbulb icon (i.e., the DATA button). Screen contrast is also set with the Fn key and appropriate buttons over icons. The shorthand used in this text for pressing Fn followed by a button is Fn & <button name>. For example, to increase the screen contrast press Fn & NAV. To bring up the overall menu of the Geo3, press Fn & OPTION.

The Sources of Power and Other Gadgets

{__} While you are exploring the receiver, get acquainted with the other paraphernalia that comes with it.

The other accessories you should find are:

- The battery charger, with two red LED indicators. You may leave the battery connected to the charger indefinitely. The battery is fully charged when the "FAST CHARGE" LED goes out.
- A cable that can connect the receiver to a computer. At the receiver end is a circular eight-pin, male plug. At the other (computer) end is a standard nine-pin RS232 serial port connector.
- Some PC computer software—named Pathfinder Office—and a printer-port hardware key, to be discussed later.
- Manuals related to the GeoExplorer: Operation Manual, Software User Guide, and a General Reference.
- A "Y" cable with two female sockets and a male plug. You may use this cable to connect the GeoExplorer directly to the battery charger, thus saving the battery when you are indoors with the unit turned on.

You have already met the rechargeable battery pack. Fully charged, it should supply more than eight hours of reception if the backlight is not used. It takes about the same amount of time to charge as it does to run down.

A second source of electricity for the GeoExplorer receiver is a detachable battery pack that holds four "AA" size batteries. Using disposable alkaline batteries, it powers the receiver for about two hours; if rechargeable batteries, or standard flashlight batteries are used, the operating time is less.

When either of the battery packs is almost exhausted, the screen fades and the receiver shuts itself down. **Almost no notice is given before thereceiver shuts off,** so treat the amount of charge in the battery pack conservatively, as you might the amount of gas in your automobile tank on a long trip, with few fueling stations along the way. For information about the battery pack (warnings, how to charge it, its ability to hold a charge while on the shelf, or replacing the "AA" cells), see the receiver operating manual.

A third option for operating the receiver is to plug the power cord into a car, boat, or aircraft DC power outlet. The connector is designed to fit a standard cigarette lighter. The acceptable range of voltage input is broad: from 9 to 32 volts. While this is a good way to power the receiver when such power sources are available, you must be careful not to start or stop the engine of the vehicle while the unit is plugged in, whether or not the receiver is off. Starting an engine, in particular, can induce voltage spikes that can damage the receiver, *even if it is turned off*.

A fourth option, usable only when you are near a 110 volt AC power source, is to connect the receiver to the battery recharger by way of the "Y" power cable. You can then review and upload files to a computer without using up battery power. You can also save battery power while configuring the GPS receiver. It might be a good idea to do this now since you have about 30 minutes of work ahead of you as you configure the receiver before you take it into the field.

The Geo3 comes with a cradle that may be connected to both a standard AC power source and to a computer. When the receiver is placed in the cradle it automatically begins recharging and data may be transferred between it and the computer.

Understanding the Screens and Controls

The process of giving commands to the GeoExplorer consists of selecting choices from a "Main Menu" and its submenus, and then pressing the CMD key. In other words, you may freely press the arrow keys without changing anything but the display. And you may "escape" from whatever menu you are viewing to a higher-level menu by pressing "Esc." When you press the CMD key you are selecting from a menu. Sometimes this simply brings up new choices. But sometimes it changes the configuration or action of the receiver.

The menu structure of the GeoExplorer is strictly hierarchical. Figure 1–5 describes it.

> The menu system for the Geo3 is explained on the CD-ROM tutorial that came with the unit. There are several routes to get to menu items on the Geo3—the menu system is not strictly hierarchical as it is in the GeoExplorer. The approach I will suggest in these boxes is to display the overall menu first by pressing Fn & OPTION. Then use the arrow keys to pick up the submenu you want.

To get to a particular menu item from the main menu, you simply select the appropriate menu items that lead to it. We first practice this by returning the receiver to its factory defaults.

{__} Make sure the GeoExplorer is on. Press "Esc" until "Main Menu" appears on the top line. On the third line of the screen you will notice a sequence of dark rectangles—flashing on and off. This is a highlight that identifies a field which may be either modified or selected by pressing buttons on the GeoExplorer.

{__} Press and hold the "down" key. Note that the main menu "scrolls" quickly, allowing you to find the item you want without repeatedly pressing the button.

{__} Press the "down" key until the highlight appears over menu item "6. Configuration." Press "CMD."

{__} **Navigate** through the menu system so you can reset the receiver to the "Factory Default" settings. To do this, press "CMD," then highlight "12.Fact Defaults." Press "CMD."

{__} You are presented with a screen that will allow you to either "Set Defaults" or "Clear Memory." If you didn't want to do either, you could press "Esc" to return to the previous menu. Instead, use the arrow keys to make sure that highlight is over "Set Defaults." Press "CMD." Resetting the receiver in this way is a fairly serious
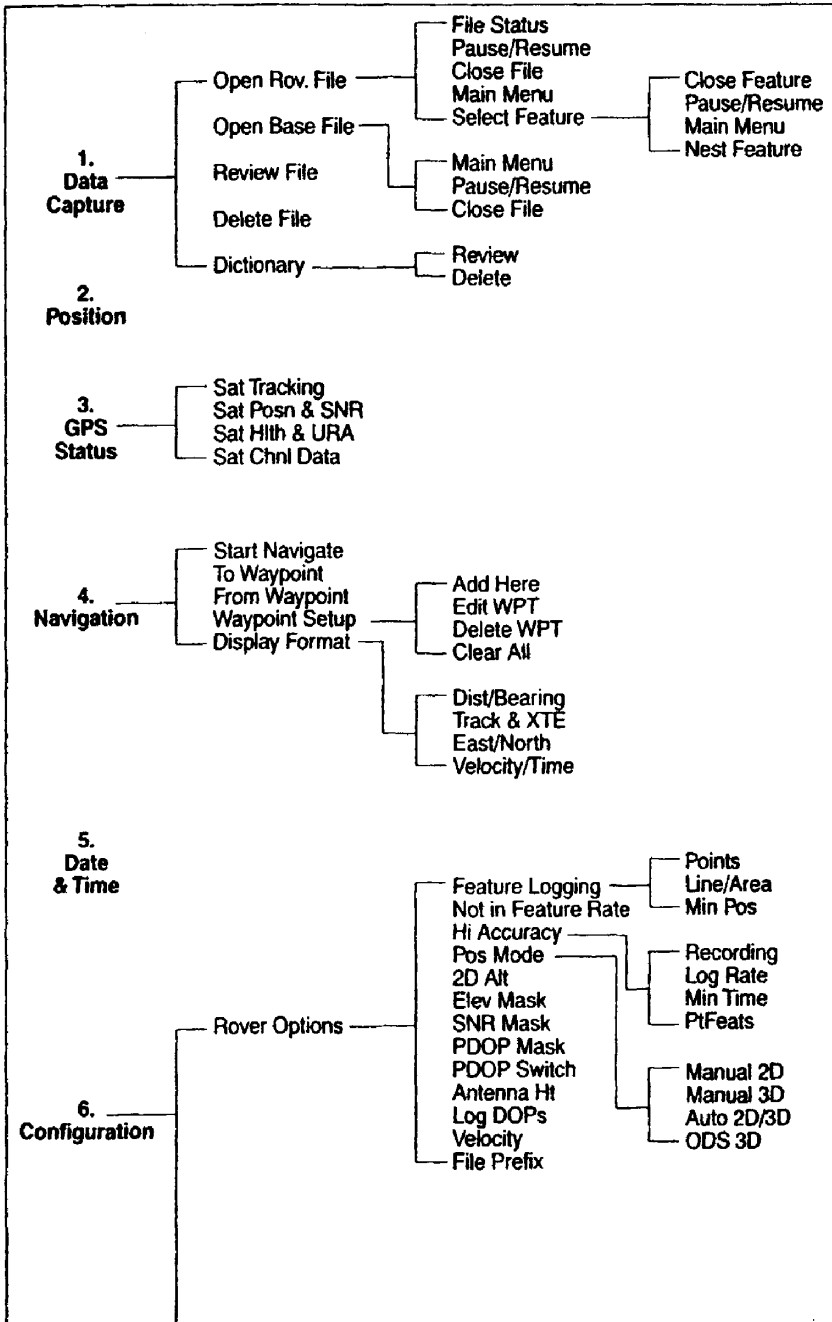
Figure 1–5. GeoExplorer menu structure.
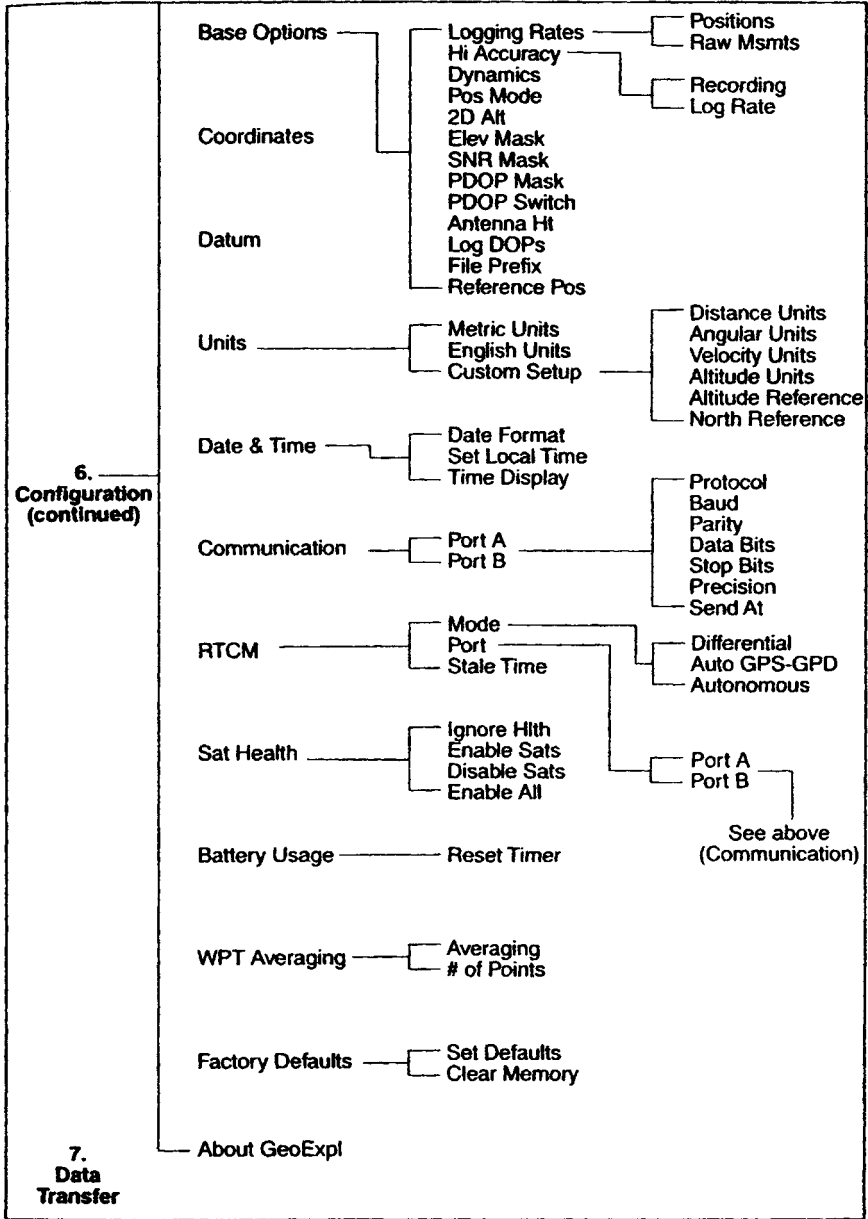
Figure 1–5. (continued) GeoExplorer menu structure.

step, so the GeoExplorer gives you a last chance to back out. Double-check that you are not about to clear the memory, then press "CMD." The message should indicate that the receiver has been reset to its defaults. Press "Esc."[14]

- Configuration -
1.Rover Options
2.Base Options
3.Coordinates
4.Datum
5.Units
6.Date & Time
7.Communication
8.RTCM
9.Sat Health
10.Battery Usage
11.WPT Averaging
12.Fact.Defaults
13.About GeoExpl

DAY mm/dd/yy
hh:mm:ss UTC
GPS Week: nnn
Local-UTC:+00:00

To reset the Geo3 to factory defaults; press Fn, then OPTION, use the arrow keys to navigate to the Setup tab, press ENTER, navigate to the Reset box, press Enter, navigate to the Factory defaults box, press Enter, navigate to the Yes box, press Enter. From now on we will use a shorthand notation for a process like this. Since there is little room for confusion between buttons and displayed options the shorthand would be: Fn & OPTION ~ Setup ~ Reset ~ Factory defaults ~ Yes.

If at times the Geo3 does not provide you with the options indicated in this textbook, repeatedly press the CLOSE button to get tothose options.

{__} Return the unit to the "Main Menu." Highlight and select "5. Date & Time." A screen something like this will appear:

On the top line you see the current day and date (actually, it's the current day and date in Greenwich, England). The world's time standard was previously called Greenwich Mean Time (GMT). The name for it now is Coordinated Universal Time, abbreviated UTC[15] and it appears on the second line of the screen. UTC is based on a 24-hour clock. The third line shows the "GPS Week."

What is it? _____. The GPS week counter starts at zero, then goes up to 1023 and then resets to zero. This resetting happened once, in August of 1999. Given the GPS week you wrote down above, about how many years would you say have elapsed since the official start of the NAVSTAR GPS project? _____. In what year was the original GPS Week number zero? ____. The fourth line is a formula which declares that "Local minus UTC time is zero." Unless you are in England, that is clearly a lie.

{__} To correct the receiver so it shows true local time, and to practice some more with menus, navigate to:

Configuration ~ Date & Time ~ Set Local Time[16]

Note the fourth line of the screen:

Local—UTC: 00:00   with a highlight flashing over the rightmost two digits. Use the "down" key to make the formula read: Local—UTC: –05:00

(This says: "Local time minus UTC time is negative five hours. Note the two negative signs.) This sets the local time to Eastern Standard Time (EST). You may reason as follows: EST is five hours earlier than UTC time. For example, when it is 11 A.M. in Greenwich it is 6 A.M. in the eastern United States. Six minus eleven equals negative five.

Greenwich time does not change when daylight savings time begins. So the difference between EDT (Eastern Daylight Time) and UTC is four hours.

{__} Using the facts above, and knowing the difference between your local time and Eastern Time, set up the correct formula on the screen. Press "CMD."

{__} Move to "3. Time Display." Select Local 12 Hours. Press "CMD."

{__} Return to "Date & Time" on the *Main Menu* to verify that they are set correctly. The time shown on this screen should be the

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[14] In very, very rare instances the GeoExplorer may lock up completely. If this happens—that is, no button pushing has any effect—remove all power from the unit (this means taking off the battery pack or the battery eliminator pack) and let the unit sit for couple of hours. When you reapply power it may have fixed itself, but it will have lost all data files and anything else in the memory.

[15] It is called UTC (rather than CUT) because it is based on international agreement and, in French, the adjective "coordinated" comes last.

[16] From now on, when you are to navigate to a certain menu item, I will use this "~" notation. For example, "Item1 ~ Item2—Item3" means: Highlight Item1, press "CMD," highlight Item2, press "CMD," highlight Item 3.

correct local time, assuming your receiver has taken data from the satellites recently. If the receiver has been indoors for some time, the time shown may be off by a few seconds. If the receiver's time differs from your local time by a large amount (fifteen minutes or more), you need to rethink the formula you entered under "Configuration."

> To set the proper time zone on the Geo3: Fn & OPTION ~ Setup ~ Configurations ~ Formats ~ Time Zone. Put in the hours difference between UTC and your time zone (remember the sign), using the arrow keys. Press ENTER. While you are in this part of the menu system you can also set the clock to 12 or 24 hours. (And, if you like, you may choose a language other than English. Take your pick of German, Spanish, French, Portuguese, or Russian. Actually, you ought to do this—say Russian—just for fun. But remember the steps (and where the displayed items are so you can get back to English, or, worst case, to Factory defaults.) When done, press CLOSE a couple of times to get back to the main Setup tab options.

{__} Write down the information under
  "Configuration ~ About GeoExpl."
  Compare this information with your notes from the screens that appeared when you turned on the GPS receiver.

> To get the general information about the Geo3: Fn & OPTION ~ Setup ~ About.

Setting Vital Parameters

Several settings under "Configuration" must be made correctly; if not, data collection may be hampered or nullified.
  {__} Go to "Configuration ~ Rover[17] Options." This is a long menu, but many of the items will not apply to your data collection at this time.

{__} Highlight the field associated with "Points" under "Feature Logging" and press "CMD." Set the logging rate to 5 seconds. Use the "up" and "down" keys to change the value, and finally press

---

[17] The word "Rover" refers to a receiver that can be moved from place to place. "Base" station receivers generally are not moved. This will make more sense later when we talk about correcting GPS signals.

Rover Options -
Feature Logging
Points
Line/Area
Min Posn
Not in Feature
Rate
High Accuracy
Recording
Log Rate
Min Time
PtFeats
Dynamics
Pos Mode
2D Alt
Elev Mask
SNR Mask
PDOP Mask
PDOP Switch
Antenna Ht
Log DOPs
Velocity
File Prefix

"CMD." (We won't use this in the early part of the text and we'd prefer to turn it off, but we can't, so we are setting it to an arbitrary value.)

{__} Highlight the field associated with "Line/Area" under "Feature Logging" and press "CMD." Set the logging rate to "Off." (We also won't use this in the early part of the text so we turn it off.) Press CMD.

{__} Highlight the field associated with "Min Posn" (meaning "Minimum Positions" under "Feature Logging" and press "CMD." Set this value to "Off." As you have figured out by now, you press "CMD" to set the value.

{__} Highlight the field associated with "Rate" under "Not in Feature" and press "CMD." Set this value to "Off."

{__} Moving on down the menu, set the High Accuracy Recording rate to "Off."

{__} Highlight the field associated with "Dynamics." Select "Sea" and note the results. Now change the dynamics to "Land" mode. The dynamics selection affects the way the receiver tracks satellites. For example, in "LAND" mode it is expected that the receiver will move more slowly than in "AIR" mode. A more complete description is provided later.

> The Geo3 does not have a Dynamics setting.

{__} Make sure the "Pos Mode" is set to "Manual 3D." This "position fix mode" should always, repeat, always, be set to "Manual 3D" unless you have enough knowledge and a particular need to set it to something else.

{__} Ignore the 2D Alt setting.

{__} Make sure the "Elev Mask" is set to "15." The elevation mask dictates that no satellite below the number of degrees (measured with the horizon considered as 0° and the zenith considered as 90°) specified will make a contribution to finding a position. For a roving receiver, as this one will be when you get it outside, a good value is 15°.

In general, a **"mask"** is a user set value. The receiver compares a given mask with another value that is automatically computed by the receiver. Based on the outcome of the comparison, the receiver uses (or doesn't use) a satellite (or a set of satellites called a **"constellation"**) in calculating a position fix. That is, a mask "blinds" the receiver to certain satellites whose signals or positions do not meet the proper criteria for good position finding.

{__} Select the "SNR Mask." Each satellite used to compute a position should have a **"Signal-to-Noise Ratio"** (sometimes referred to as signal strength) of four or greater. Verify or set this parameter correctly.

{__} Set the PDOP Mask to "6."

We will explain the "PDOP" (Position Dilution Of Precision) term later. For now, just be aware that any PDOP over eight is unacceptable, and four is a figure to use for really precise positioning finding.

{__} Ignore the PDOP Switch.

{__} Set the Antenna Ht (antenna height) at one meter, since that is about how far you will be holding the antenna over the point whose position you are trying to determine.

{__} Ignore Log DOPs, Velocity, and File Prefix.

> The Geo3 allows you to set most of the options described above. Getting to the right menu items is, of course, done in a different way. Basically, you want to go: Fn & OPTION ~ Configurations. Some of the various settings may be made under Fn & OPTION—Configurations ~ Data. Others are made under Fn & OPTION—GPS ~ OPTION—Advanced mode. The CLOSE key will come in handy at times.

Preparing to Correlate GPS Data with Map Data

{__} Take out the USGS topographic quadrangle (a topo map, usual scale 1:24,000) of the appropriate general area. The receiver can display a geographic position in several coordinate systems. Under "Configuration ~ Coordinates" you will find

- Degrees, Minutes, and decimal fractions of minutes (Deg &Min)
- Degrees, Minutes, Seconds, and decimal fractions of seconds (Deg, Min & Sec)
- Ordinance Survey of Great Britain (OSGB)
- Universal Transverse Mercator (UTM)
- Earth Centered, Earth Fixed (ECEF)
- Trimble Grid

{__} Choose "Deg & Min."

{__} Under "Configuration ~ Datum" you will find a list with a large number of choices, stored in alphabetical order. You can scroll through the list by holding down either the "up" key or the "down" key. Choose Bahamas[18] (NAD-27) with the "CMD" key.

{__} Then choose WGS84 (World), which is the fundamental GPS datum. **WGS84** identifies the World Geodetic System developed in 1984.

{__} Finally, note the datum of the map you are using. The datum is usually found in the lower left-hand corner (e.g., NAD27, the North American Datum of 1927). Under "Configuration ~ Datum" set the GPS receiver to operate in this datum, shown as "N-Am. 1927 Conus" if this is the datum of your map—as it is with many USGS topographical maps.

> To set these options with the Geo3 you use Fn & OPTION—Setup ~ Configurations ~ Coordinates. The Geo3 contains an annoying number of Datum choices. If you hold down an arrow key it scrolls through

them— not quickly, but it beats wearing out your thumb and the switch. A shortcut: the datum choices are in alphabetical order; the list wraps around the end (i.e., "A" comes after "Z").

   The other options you need to set in this section are under Fn & OPTION—Setup ~ Configurations ~ Units.

- Custom Setup -
1.Distance Units
2.Angular Units
3.Velocity Units
4.Altitude
5.Alt Reference
6.North Reference

{__} Under "Configuration ~ Units ~ Custom Setup" you will find this menu:

{__} Under "Distance Units" choose Kilometers. Distance units available on the GeoExplorer include Yards, Meters, Kilometers, **NauticalMiles** (6080 feet), Miles (statute, 5280 feet), "Internatl Feet" (**international feet,** where an inch is 0.0254 meters, exactly), and **"U.S.Survey Feet"** (where a meter is considered to be 39.37 inches, exactly).

   {__} Examine your map to determine the appropriate distance units for the upcoming fieldwork. Feel free to change this value later if you should wish visual output in some other units.

   {__} Under "Configuration ~ Units ~ Custom Setup ~ Altitude Units" choose Meters or Feet, depending on the map you will be using.

   {__} Under "Configuration ~ Units ~ Custom Setup ~ Altitude Reference" choose Geoid (MSL). The "altitude reference" may be set to either MSL (which is elevation above Mean Sea Level) or HAE (which is Height Above the reference Ellipsoid—the theoretical mathematical surface that approximates the surface of the Earth). Since at this time you probably do not know the relationship between the HAE and MSL at your location, you are selecting MSL.

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[18] We can dream, can't we?

{__} Under "Configuration ~ Units ~ Custom Setup ~ North Reference" choose "North, True" or "South, True" depending on the map you will be using.

Double-Checking the Configuration

{__} Now do a summary check of the configuration. Under the menu choice "Main ~ Configuration" check the following critical options:

- Rover Options ~ Dynamics: Land
- Rover Options ~ Pos Mode: 3D
- Rover Options ~ Elev Mask: 15
- Rover Options ~ SNR Mask: 4
- Rover Options ~ PDOP Mask: 6
- Rover Options ~ Antenna Ht: 1.00 (or your waist height in meters)
- Rover Options ~ Log DOPs: Off
- Rover Options ~ Velocity: Off
- Rover Options ~ File Prefix: (do not change)
- Rover Options ~ Not in Feature Rate: Off
- Coordinates ~ Deg & Minutes (and decimal fractional parts thereof)
- Datum: (set to your map)
- Units ~ Custom ~ Distance: (set to your map)
- Units ~ Custom ~ Angular: Degrees
- Units ~ Custom ~ Velocity: Kilometers per Hour
- Units ~ Custom ~ Altitude Units: (set to your map)
- Units ~ Custom ~ Altitude Reference: Geoid (MSL)
- Date & Time ~ Set Local Time: (adjust to local time)
- Date & Time ~ Time Disp: Local 12 Hours
- Battery Usage: (reset if battery freshly charged)

Use this checklist each time you take the GeoExplorer into the field — modifying it as necessary.

Final Inside Activity

You are almost ready to take the GeoExplorer into the field. One thing remains to be done. While you are still inside, read through the directions for PROJECT 1B below completely to prepare yourself for the fieldwork. Develop a feel for the sort of data you

will be collecting. Practice changing from screen to screen. Outside, with the wind blowing and the traffic roaring, is no time to discover that you don't have a solid surface to write on or that you don't know just what it is you are supposed to be doing. A little preparation now will pay big dividends later.

> If you are going to collect data with the Geo3 you also need a square about 2.5×2.5 inches made of a couple of layers of aluminum foil. And a few inches of masking tape.

{__} Read over PROJECT 1B below.

PROJECT 1B

Now Outside

This is an exercise best done with two people. You will take the map, your notebook, and the GPS receiver outside to make observations. You will not yet place the data you collect into a computer file but you will learn a lot about the factors affecting data collection. (If you are not sure that the set tings on the receiver are those you put in during Project 1A, verify them against those in the previous section: "Double-Checking the Configuration.")

{__} As you leave the classroom or laboratory to travel to the site for data collection, turn the unit on. If you carry the receiver exposed to the sky, it will begin to "acquire" satellites. **It is_not_important whichmenu appears on the display; whenever the receiver is on, it "looks"for satellites and calculates positions if it can.**

{__} Move to a spot outdoors, well away from buildings and heavy tree canopy. If it is reasonably level and not shrouded by nearby hills or mountains, so much the better. And if you can locate the antenna over a geodetic monument, for which you can find the official latitude and longitude (perhaps from the NGS web site, www.ngs.noaa.gov), super.

{__} Look at the map to locate your approximate position.

{__} Hold the antenna over the spot for which the coordinates are to be determined. The antenna in the receiver is just below the image of the sextant embossed in the plastic of the top of the receiver. Hold the unit as far in front of you as is comfortable, with

- GPS Status -
1.Sat Tracking
2.Sat Posn & SNR
3.Sat Hlth & URA
4.Sat Chnl Data

the top part close to horizontal, tilted only enough so you can read the screen.

Actually, no position will be comfortable after a few minutes; you will want to pass the unit to your partner so you can drop your arm and let the blood drain back into your fingers. An alternative is to put the unit on the ground and crouch or sit down so you can read the screen. This is less fun in winter, or when there is poison ivy about. I never claimed fieldwork was easy. You might bring a table or tripod with you, or find a fence post. Be careful: the power cord makes it easy to bounce the receiver off the ground. It's a tough unit but it is also expensive; do you really want to test it?

{__} Keep your head and body out of the way, i.e., don't block the signal from a satellite to the receiver. You are opaque, as far as the high-frequency, short-length GPS waves are concerned. Remember, the receiver is looking for satellites as low as 15 degrees above the horizon. It's easy to forget this and obstruct the antenna, causing the receiver to lose its lock on a satellite.

Tracking Satellites

{__} Starting with the Main Menu, navigate to the "GPS Status" menu and press "CMD." The following will appear:

Highlight "Satellite Tracking" and press "CMD." The "Sat Tracking" screen will appear, listing some two-digit numbers. These are the designations, called **PRN numbers,**[19] that your GPS receiver uses to identify the satellites. The numbers lie between 1 and 32, inclusive.

The numbers that appear now are those of the satellites that the receiver might be able to pick up, based on your position and time. They are usually those which are above the horizon and the specified elevation mask angle. The receiver determines which satellites are available by formulas built into its computer and by an **almanac** transmitted by each satellite which describes the general location of all the satellites.

Since you are outside, presumably the receiver is locked onto some satellites. The number of little shaded boxes in the lower left-hand corner of the screen indicates how many. The receiver needs to be receiving at least four satellites before location fixes are computed.[20] Because the geometry when the elevation angle is set at 15° allows the receiver to consider satellites in about one-third of the sky, it may track eight satellites, or even one or two more.

One more bit of information may be learned from this screen. Small arrows—up to four of them—may be seen pointing to satellite numbers. These are the satellites which the receiver is using (or attempting to use) to calculate its position.

To summarize the screen:

- If a satellite's number appears on the screen, then, according to the almanac the satellite should be physically in the space above the user, at an angle greater than the setting of the elevation mask. This would theoretically make the satellite available for position finding.
- If an arrow appears next to the number, the satellite is being considered for position finding. If a position is found, the satellite is being used for position finding.
- The number of little boxes indicates the number of satellites that the receiver is tracking, that is, electronically locked onto.

> The Geo3 display is much different—actually much easier. Go Fn & OPTION ~ GPS. By using the OPTION button you can toggle between the Standard screen and the Advanced screen. The Standard screen shows a skyplot of the satellites that are being used for position finding, that are being tracked, and that could be tracked. It also, most importantly, shows the coordinates of the antenna of the receiver. The Advanced screen shows a table of satellite information. A check mark indicates the satellite could be or is being used to compute positions.

{__} A few minutes may elapse before the unit locks onto enough satellites to begin giving position fixes. If more than 10 minutes go

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[19] "PRN" stands for "Pseudo Random Noise" (no doubt just the designation you expected for the satellites). I will explain later.

[20] If the receiver is in 2D mode, only three satellites are required for a location fix. But unless you have entered the precise altitude of the antenna, the locations calculated by the receiver will be wrong. Again, don't use 2D mode unless you know what you are doing.

by with no position fix, change the PDOP to eight (8) and make sure you aren't obstructing the signal.

{__} Once the GeoExplorer is tracking four or more satellites, select "Position" from the Main Menu and write down the latitude, longitude, and altitude. When locked onto four or more satellites, the receiver computes the position of the antenna about three times every two seconds. (If the word "OLD" appears on the screen it indicates that the value presented is one that was collected in the past—perhaps the immediate past—and that the receiver is not calculating new positions. Make certain that there are no obstructions blocking the signals.)

{__} Note the time. Plan to write down a new position reading in your notebook every minute, approximately on the minute, for the next quarter of an hour.

{__} In between writing position fixes in your notebook you should record some other information. Move back to the "Sat Tracking" screen. Note down the numbers of the satellites which appear there. Circle the numbers of the satellites the receiver is using to compute positions. Also note how many satellites the unit is receiving signals from. Write down the value identified as "PDOP."

{__} Now it is probably about time to go back to the "Position" screen to write down the next set of position coordinates. They should be close to, but not exactly the same as, those you wrote down a minute ago. The screen should not say "Old Position." If it does, you probably got your head in the way of a satellite signal.

{__} Now go to the "Sat Posn & SNR" screen (it's under "GPS Status"). You will see several horizontal lines of information—one for each satellite being tracked. One item of information displayed for each satellite is **"Elv"**—an abbreviation for **Elevation**. If you could stand and point a straight arm directly toward the satellite, the elevation would be the angle, in degrees, that your arm made with the Earth, assuming the surface is level where you are standing. Zero degrees would represent a satellite at the horizon; ninety degrees would represent a satellite directly overhead.

{__} Whoops. Time to write down another lat-lon-alt position.

{__} Return to the "Sat Posn & SNR" screen. The column after "Elv" is identified as **"Az"** which stands for **Azimuth**. The Azimuth specifies the angle between due north and the satellite: Point your arm toward the north, then rotate your body clockwise until your arm is pointed at the satellite. The number of degrees your body rotated is the azimuth.

{__} Write down another position fix.

The last column on the "Sat Posn & SNR" screen is the "signal to noise ratio" (recall that it is an indication of the strength of the signal from the satellite). Acceptable values are greater than or equal to four—which is the value you set as the SNR mask. Values may range up to 35 or so.

{__} For each satellite being tracked, record its elevation, azimuth, and signal strength.

{__} Put your hand over the antenna (it is directly under the little sextant embossed in the plastic above the screen) and watch the signal strength drop.

{__} Determine where one or two satellites are in the sky, relative to your position. Try to interpose your body between the unit and a satellite to see if you can make the signal strength drop for a single satellite. In the middle latitudes in the United States there will generally be more satellites to your south than north

{__} After recording another fix, move to the "Sat Hlth & URA" screen. This displays the "health" of the satellite, as determined by information broadcast by the satellite itself, and the "User Range Accuracy" (URA)—a numerical indication of the accuracy one might expect when using this satellite to compute a position fix. Satellite health will be indicated by "OK," by "U" for unhealthy, or by "n/a" for "not available," indicating that no signal is being received.

"URA" may have values ranging from one to 1024. Values greater than 16 indicate that the DoD is corrupting the signal for the particular satellite and that any single point calculated by using that satellite could be in error by approximately 100 meters. This is not supposed to happen after May Day 2000 so the URA values should be on the order of two to three. The units of the URA number are meters, but since a given position is found using a combination of several satellites, the URA value of any particular one is of limited usefulness in estimating error.

> The Geo3 does not display User Range Accuracy.

{__} Finish recording the 15 position fixes. Is the unit still tracking the same satellites? Is it using the same constellation of satellites to compute fixes? If not, write down the new information.

Set Your Watch

{__} The GPS receiver's clock has been correctly set by the exposure to the satellites. It now has a very accurate idea of the time. So you may set your watch by it and be correct to the nearest second.[21] With the recording of the geographic coordinates and the setting of your watch, you have used GPS to position yourself in four-dimensional (4D) space.

> Time on the Geo3, assuming that it has been properly configured for the local time, is found by Fn & OPTION ~ Chart. If the time doesn't show up, press OPTION ~ Info windows. Put a check by "Current time" with the ENTER key, (You might have to uncheck something else to make room for the time window.) Press CLOSE.

(As you may or may not know, Einstein's general theory of relativity predicts that time runs more slowly the greater the gravitational field—a somewhat amazing claim that has been verified. That is, a clock would run faster far out in space, away from any large masses, than it would here on earth. An animal would age more quickly. It turns out that, while the effect is tiny for GPS satellites, their clocks are far enough away from Earth so that they do run at a different rate than those here, and this difference has been compensated for.)

Did the Earth Move?

{__} Go to the "Navigation" item on the Main Menu. When you select it you will find five menu items, as shown below:

1.Start Navigate
2.To Waypoint
3.From Waypoint
4.Waypoint Setup
5.Display Format

{__} Select "Display Format." Select "Velocity/Time." The display returns to the "Navigation" menu. Select "Start Navigate." Scroll the screen until "Vel:" (for Velocity) appears. A number,

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[21] The UTC time known by the GPS receiver is correct to a few billionths of a second, but the display is not nearly that accurate.

representing kilometers per hour (kph), is displayed. The number will be between zero and around 0.4.

Any number greater than zero indicates that the antenna is moving at some number of kilometers per hour with respect to the Earth. That's odd. You see that the antenna is virtually motionless. Why should the receiver be recording movement? The answer is that, with any physical system, there are errors. Your GPS receiver is calculating positions at the rate of about three every two seconds. Since each position differs, slightly, from the one before it, the receiver believes that its antenna is moving.

{__} Now begin to walk with the unit held out in front of you. Call out the velocity readings to your partner. He or she should "mentally" average your readings and record some values. A comfortable walking speed is about five kph (three miles per hour). Is that what the unit indicates?

{__} Continue to walk. Escape from the current screen and select "Display Format" again. This time pick "Dist ~ Bearing." Select "Start Navigate" again. Scroll the screen until "Heading:" appears. The number indicates your direction of travel, relative to True North ("Tn"), in degrees. Again, call the readings out to your partner. Do they tend to average to the approximate direction you are walking?

> One way to navigate with the Geo3: Fn & OPTION ~ Compass ~ OPTION—Info Windows. With the up and down arrow keys and the ENTER key, turn on Heading, Velocity, and Current time. Scroll down to be sure everything else is turned off, Then begin to walk.

{__} Walk back to the original location where you recorded the position fixes. After a minute or so, shut the unit off and return to your lab, room, or office. Be certain the screen is blank, so that the unit is not collecting new position fixes. Disconnect the power cord from the battery **(not from the GPS unit)**. Do not turn the unit on again until you are inside a building, because in the next Project we will want to use the last position that was recorded by the receiver. The coordinates of that position will be remembered by the receiver.

> If you turn it off, the GeoS loses the last position, so you cannot do Project 1C. Therefore, leave the Geo3 turned on (be sure the backlight is off so as to save the battery). Tape the square of aluminum foil over the top of the unit—where the antenna is—so it can't continue to take

> data. Back in your room, office, or lab begin the Project below immediately.

PROJECT 1C

Back Inside

Your session in the field may have raised as many questions as it answered. We will look at the answers to those questions in later chapters. First, let's verify that GPS really works. (Someone is telling you that you can find your position on Earth to within a few feet from four objects in space, more than 12,000 miles away, batting along at 2.4 miles per second. Would you believe them without checking? I wouldn't.)

{__} Using a calculator, obtain the average of each of the 15 latitudes, 15 longitudes, and 15 altitudes you recorded.

Average Latitude_____

Average Longitude_____

Average Altitude_____

Plot the point on your topo map. Does the point represent where you were?

The average altitude indicated developed by GPS is likely to be somewhat different from that shown by the map. The horizontal accuracy of a single point is usually within 10 meters, or roughly 33 feet. Vertical accuracy is about half or a third that good. So your altitude fix that your receiver recorded at any given point could be off by 70 to 100 feet. The average of the 15 altitudes should be somewhat better.

The Shape of the Earth—Finding Elevations

In terms of trying to find a mathematical or textual description of its shape, Earth is a mess. Even not considering its obvious bumpiness—clearly evident to you if you only look out a window—the overall shape defies any attempt at neat description. The wonderful idea that Earth was the simplest of all three-dimensional figures—the sphere—bit the dust in 1687 when Newton proposed that an ellipsoid was a better approximation. Thus the Earth was considered to more resemble a ball, compressed slightly at the poles, with greater girth at the equator.

The diameter through the poles is some 43 kilometers less than a diameter across the plane of the equator.

In the latter part of the twentieth century it was determined that the shape departed from ellipsoidal as well. A slight depression at the south pole complements a little protuberance at the north pole, and just south of the equator we find a bulge. So how can a cohesive description be made? By careful mathematical work, based on gravity and water.

A definition: The **geoid** is a surface, like an egg shell. It is equipotential (that is, everywhere on the surface the strength of gravity is the same) and (almost) coincides with mean sea level. Imagine that all seas are calm, and mean sea level extends through the land forms through a network of canals. (In reality, mean sea level, itself, can vary by a meter or two, depending on where it is measured.) The geoid surface, by definition, is perpendicular to the force of gravity, no matter at what point it is considered. Because the value of gravity varies over the surface of the Earth, the surface of the geoid is smooth and continuous, but not regular as a sphere or ellipsoid would be. It has depressions and bulges.

Satellites are kept in their orbits by gravity. Gravity can be considered a force between the satellite and the center of mass of the Earth. The GPS satellites are not affected by the shape of the Earth nor variations in its density. They orbit around its center of mass and are a long way away. This provides the opportunity to define a simple mathematical surface that approximates the surface of the Earth. The **reference ellipsoid** is this surface—created by rotating an ellipse around the axis connecting the poles. The center of the ellipse, and hence the center of the ellipsoid, is the center of mass of the Earth. The surface of the ellipse is meant to approximate the geoid. Some places the reference ellipsoid surface is below the geoid and some places it is above.

Compare the Two Altitude Referencing Systems

For all but the last few years, most people measured altitude from the average level of the oceans. The two primary methods of taking measurements were vertical length measurement from a beach (inconvenient if no ocean were nearby) and measurement of air pressure. Of course, air pressure is variable from hour to hour so there are complications using this method as well.

As previously mentioned, a new definition of altitude has been developed, using not sea level as the zero but the gravitational surface called the reference ellipsoid. As I just said, the reference ellipsoid approximates mean sea level, but is slightly different from it almost everywhere. Since the satellites are slaves to gravity, the GeoExplorer "thinks" of altitude and elevation in terms of **height above the reference ellipsoid (HAE)**.

Of course almost all data related to altitude, garnered over several hundred years, is expressed in altitude above mean sea level (MSL). So formulas and tables have been developed that indicate the difference between MSL and HAE. These are incorporated into the GeoExplorer receivers so they may display altitude in MSL. You will examine HAE and MSL in your area by doing the following:

{__} Reconnect the battery to the power cord to the GPS unit. Turn the GPS unit on. **The receiver kept in its memory the coordinates ofthe last data point you took in the field; the coordinates of this pointcan be displayed from the "2. Position" menu item in the Main Menu.The screen heading will be "Old Position."** Now determine the approximate difference between Mean Sea Level and the Height Above Ellipsoid in your area. (The manufacturer of the receiver coded the information in your receiver for all locations on the earth's surface.) The idea is that you will first display the Old Position in MSL, then display it in HAE.

First, write down the elevation of the last point (the OLD position) from the "Position" screen. This will be a height above sea level in feet or meters, depending on how you set the units. Now under Configuration ~ Units—Custom Setup ~ Alt Reference select "Ellipsoid (HAE)." Return to the "Position" screen. A different number will be shown for elevation. This new number is the height of the OLD position above the reference ellipsoid. From these two numbers you can calculate the difference in height between the reference ellipsoid and mean sea level. What is it and in what units? _____. Which is higher? _____.

> To see the difference in MSL mid HAE altitudes using the Geo3: First record the altitude shown on the screen that shows you the latitude and longitude coordinates (Fn & OPTION ~ GPS using the Standard screen). The altitude will appear at the bottom of the screen, alternating with a couple of messages. You will be writing down the altitude above Mean Seal Level (MSL), To determine the Height

> Above Ellipsoid: Fn & OPTION ~ Setup ~ Configurations ~
> Coordinates—Altitude reference ~ HAE. (Make sure the altitude units
> and coordinate units are set to Meters.) Return to the screen from
> which you found the MSL altitude earlier.

{__} Turn the GPS unit off. Read the following section carefully!
Twice! [If you are using the Geo3, don't turn the unit off.]

The Datum Makes a Difference

**It is absolutely vital, when integrating GPS data with GIS
data, thatyour data sets match with respect to geodetic
datum,**[22]**coordinate system, units, and projection.** You will
soon prove to yourself how important this is by filling out the
Latitude and Longitude Computation Tables at the end of this
chapter and noting the differences between different systems. You
will need to use the following four points of information to
determine the differences in position designation from one datum
to another, and from one coordinate system to another:

- One degree of latitude corresponds to approximately 111
  kilometers (km); therefore one minute of latitude corresponds to
  that number divided by 60, or approximately 1,845 meters.
- The length of a minute of longitude, measured along a parallel,
  depends upon the **latitude** of that parallel. The length varies
  from approximately 1,855 meters at the equator to zero meters
  at the poles. So some computation is needed: at the latitude at
  which you took data (what is it? _____), one minute of
  longitude corresponds to approximately 1,855 meters multiplied
  by the cosine of that latitude. For example, if your latitude were
  30° the value of the cosine would be approximately 0.866.
  Therefore a minute of longitude would correspond to 1,601
  meters (that's 1,855 times 0.866=1,601). Now do the calculations
  for your latitude: At the position of your fix, a minute of
  longitude corresponds to _____ meters.
- On the Trimble display, the position information in Universal
  Transverse Mercator (UTM) is given with easting (the x-
  coordinate) first, and northing (the y-coordinate) second. **Note**

---

[22] "Datum" is the master geodetic referencing system used for a particular
project or map.

> **that thisis opposite the "latitude first" convention of "Deg & Min."**

- In the UTM coordinate system, in a given zone, a greater number of meters indicates a more easterly position in longitude, or a more northerly position in latitude. That is, "x" and "y" increase "to the right" and "up," respectively, in accordance with standard Cartesian convention.

{__} Turn the GPS unit on. Make certain the receiver is not taking data from satellites. Fill out the Latitude and Longitude Computation Tables below. To do this, you will have to obtain eight numbers from the GPS unit **when it is not taking data from satellites** (e.g., while inside or with a couple of layers of aluminum foil taped over the antenna). The receiver kept in its memory the coordinates of the last data point you took in the field; as before (with the altitude computation you did), these can be displayed as the Old Position. Let me say that again: **The receiver kept in its memory the coordinates of thelast data point you took in the field; these can be displayed as theOld Position.**

The Geo3 will only display the last position it took if it is left on from the last time it took data from the satellites. If you have turned it off in the meantime you need to take it back outside and have it calculate a position.

You can view both coordinates of that point in several ways, using whatever datum you want and in whatever coordinate system you want. You may obtain the first two of the eight numbers by setting the configuration to, say, latitude & longitude and NAD27, then switching to the Position screen and writing down the numbers in the appropriate spaces on the appropriate tables at the end of the chapter. Then change the datum to WGS84, go to the Position screen and write down those numbers. Next do UTM and WGS84. Finally do UTM and NAD27. When you have finished writing down the coordinates and doing the calculations on the forms, come back and answer the question below:

{__} Does the difference in meters from WGS84 to NAD27 using the UTM coordinate system correspond to the difference in meters you calculated based on latitude and longitude degrees and minutes? _____. What conclusions can you draw from your observations and calculations?

_____

_____

_____

With the Geo3, the screen you need to use to write down the required numbers is Fn & OPTION ~ GPS, in Standard mode. To get to the different coordinate systems and to where you can set the Datum you use:

Fn & OPTION ~ Setup ~ Configurations ~ Coordinates ~ System to set Latitude and Longitude,

Fn & OPTION ~ Setup ~ Configurations ~ Coordinates ~ System to set Universal Transverse Mercator, after which you must set the Zone to your UTM zone, e.g., 16 North (available from the topo map), and

Fn & OPTION ~ Setup ~ Configurations ~ Coordinates ~ Datum.

Latitude[23]
COMPUTATION BASED ON THE
SINGLE"OLD" POSITION

~~~~~~

Degrees & Minutes

NAD27 _____ (N-Am. 1927)

WGS84 _____

Difference _____

In your area, the representation in "Deg & Min" of the point in WGS84 (alias NAD83) is _____ minutes (north or south) _____ of the representation of that point in NAD27.

This corresponds to _____ meters.

~~~~~~

UTM (in meters)

NAD27 _____

WGS84 _____

Difference _____

In your area (which is UTM Zone: Number ___, Letter ____), the representation of the point in UTM coordinates based on WGS84 is _____ meters (north or south) _____ of the representation of that point in UTM NAD27.

~~~~~~

---

[23] Text versions of all forms in this book may be found on the accompanying CD-ROM in the folder named FORMS. Users are invited to modify and print the forms for their own use.

Longitude
COMPUTATION BASED ON THE
SINGLE "OLD" POSITION

~~~~~~

Degrees & Minutes

NAD27 _____

WGS84 _____

Difference _____

In your area, the representation in "Deg & Min" of the point in WGS84 (NAD83) is _____ minutes (east or west) _____ of the representation of that point in NAD27.

This corresponds to _____ meters.

~~~~~~

UTM (in meters)

NAD27 _____

WGS84 _____

Difference _____

In your area (which is UTM Zone: Number ___, Letter ___), the representation of the point in UTM coordinates based on WGS84 is _____ meters (east or west) _____ of the representation of that point in UTM NAD27.

~~~~~~

GPS Equipement Checkout Form

We (please print names, telephone numbers, E-mail addresses)

_____, _____, _____

_____, _____, _____

wish to check out the GPS receiver:

( ) GeoExplorer   ( ) Geo3   ( ) Other _____

on _____   ____/____/____ at _____   _____.
  (day)   (date)   (time)   (place)

We understand that this equipment is valuable, and we will use our best effort to guard it against damage, loss, or theft.

We intend to take data at _____

which is at approximately latitude _____

and longitude _____ .

We will return said equipment

on _____   ____/____/____ at _____   _____.
  (day)   (date)   (time)   (place)

_____   _____

(signed)   (signed)

In case of difficulty in returning the equipment we will contact _____, at phone number _____ We will leave a message on the recorder if there is no answer.

_____

Office Use:

Unit # _____ checked *OUT* at _____ on _____ by _____

Unit # _____ checked *IN* at _____ on _____ by _____

2
Automated Data Collection

IN WHICH you learn the basic theoretical framework of GPSposition finding, and practice using a GPS receiver tocollect computer-readable data.

OVERVIEW

How'd They Do That?

By now you have determined that GPS really works. That little gadget can actually tell you where you are! How?!

The fundamentals of the system are not hard to comprehend. But mis-conceptions abound, and it is amazing how many people don't understand the principles. In a few minutes, assuming you keep reading, you will not be among them.

We look first at a two-dimensional analogy. You are the captain of an oceangoing ship off the western coast of some body of land. You wish to know your position. You have aboard:

- an accurate timepiece;
- the ability to pick up distant sound signals (a megaphone with the narrow end at your ear, perhaps?);
- a map showing the coast and the locations of any soundhouses (a soundhouse is like a lighthouse, but it emits noise instead); and
- the knowledge that sound travels about 750 miles per hour, which is about 20 kilometers (km) per minute, or 1/3 km per second.

Suppose:
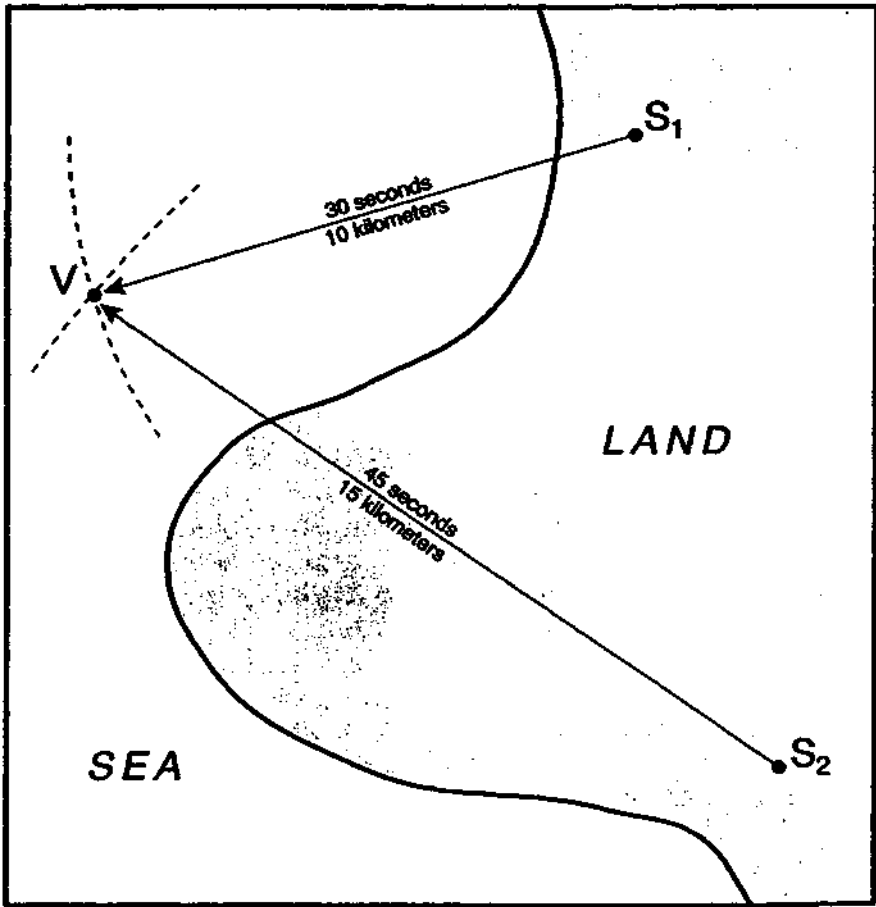
Figure 2–1. Measuring distance by measuring time.

1. There is a soundhouse located at "S1" on the diagram in Figure 2–1.
2. Each minute, exactly on the minute, the soundhouse horn emits a blast.

With these elements, you can determine the distance of your vessel, "V," from the soundhouse. To do so, you note when your clock marks an exact minute. Then you listen for the sound signal. When it comes, you again note the second hand of the clock. You then may calculate "d" from

$$d = s/3$$

where "d" is the distance in km from the soundhouse and "s" is the number of seconds it took for the sound to reach you.

Suppose it took 30 seconds for the signal to arrive. You would know your ship was 10 km from soundhouse S1.

In geometric terms, you know only that your ship is located somewhere on the surface of a sphere that has a radius of 10 km. You can reduce this uncertainty considerably since your ship is floating on the ocean, so you know your altitude is fairly close to mean sea level (MSL). Thus you could consider yourself to be on a circle with a radius of 10 km.

That, however, does not pinpoint your location. And, by looking at the diagram, you can see that, if you are moving, you might be in a lot of trouble, since contact with the ground is not recommended for ships. How could you determine your position more exactly? By finding your distance from a second soundhouse.

Suppose you use the same technique as above, listening to soundhouse "S2." You find it is 15 km away. Then the question is: where is (are) the point(s) that are 10 km away from "S1" and 15 km away from "S2"? If you solve this problem graphically, by drawing two circles, you find they intersect in two places. One of these locations you can pretty well eliminate by noting that your ship is not sitting on a prairie or in a forest. Based on the measurement from the second soundhouse, you know your position as accurately as your measuring devices and map will let you know it.

It is obvious that you can find your position by drawing circles. You can also find your position by purely mathematical means. (You would determine the coordinates of the intersection of the two circles from their formulas by solving two "simultaneous" equations. Then you would consider lengths of the sides of the triangle formed by the two soundhouses and the ship. This process is sometimes called "trilateration." (A triangle is a "trilateral," as a four-sided figure is a "quadrilateral")

As with the soundhouses, distances—determined by the measurement of time—form the foundation of GPS. (Such distances are referred to as ranges.) Recall the basis for the last three letters of the acronym NAVSTAR: Time And Ranging.
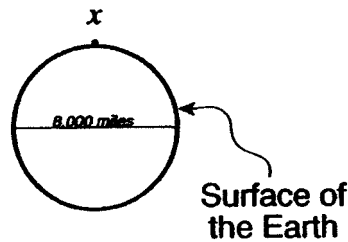
Figure 2–2. Earth and a point to be found.

How It Works: Measuring Distance By Measuring Time

How do the concepts illustrated above allow us to know our position on or near the earth's surface? The length of that answer can vary from fairly short and simple to far more complicated than you are (or I am) interested in. At its most detailed, GPS is rocket science, brain surgery, nuclear physics, and the theory of relativity all rolled into one.

Basically, distances to several satellites (four are needed for a good 3-D spatial fix) are calculated from measurements of the times it takes for radio waves to reach from the satellites, whose positions are known precisely, to the receiver antenna.

To illustrate, let's look at these basic ideas by seeing how the "ship" example differs from NAVSTAR.

- NAVSTAR gives us 3-D locations: Unless we are in fact on the sea, in which case we know our altitude, the problem of finding our location is three-dimensional. GPS can provide our position on or above the earth's surface. ("Below" is tricky because of the radio wave line-of-sight requirement.) But the method translates from two to three dimensions beautifully.
- The "soundhouses" are satellites: Rather than being situated in concrete on a coast, the device that emits the signal is a satellite, zipping along in space, in an almost-exactly-circular orbit, at more than two miles per second. It is important to note, however, that at any given instant the satellites **(space vehicles,** or SVs) are each at one particular location.
- NAVSTAR uses radio waves instead of sound: The waves that are used to measure the distance are electromagnetic radiation (EM). They move faster than sound—a lot faster. Regardless of
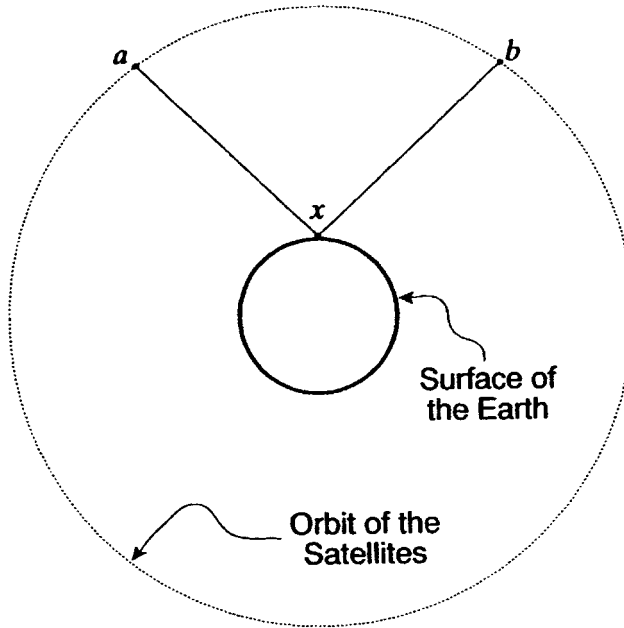
Figure 2–3. The Earth and GPS satellites.

frequency, in a vacuum EM moves at about 299,792.5 km/sec,
which is roughly 186,282 statute miles per second.

Let's now look at the configuration of GPS with a drawing of true
but extremely small scale, starting with two dimensions. Suppose
we represent the earth not as a sphere but as a disk (like a coin),
with a radius of approximately 1 unit. (One unit represents about
4000 statute miles.) We are living on the edge (pun intended) so we
are interested in points on, or just outside (e.g., airplanes and
orbiting spacecraft) the edge of the coin. We indicate one such
point by "x" on the diagram of Figure 2–2. We want to find out
where "x" is.

Suppose now that we have two points on the drawing of
Figure 2–3, called "a" and "b." They represent two of the
NAVSTAR satellites, such that we can draw straight lines from "a"
to "x" and from "b" to "x." We require that the lines not pass
through our "Earth." These points "a" and "b" are each about four
units from the center of the coin (thus three units from the edge of
the coin).
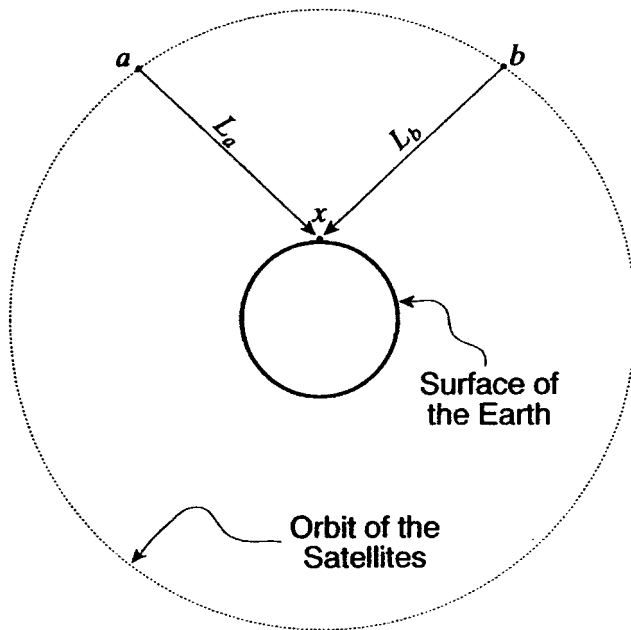
Figure 2–4. Distances from "x" to the GPS satellites.

Measure the distance, or length, from "a" to "x" (call it "La") and from "b" to "x" (call it "Lb"). The lines "La" and "Lb" represent the unobstructed lines of sight from the satellites to our receiver antenna. If we know the positions of "a" and "b" and the lengths of "La" and "Lb" we can calculate the position of "x" through the mathematical process of trilateration[1] shown in Figure 2–4.

It is intuitively obvious that we can locate any "x," given knowledge of the positions of "a" and "b," and of the lengths "La" and "Lb": "x" must lie on a circle centered at "a" with radius "La" and also must lie on another circle centered at "b" with radius "Lb."

To formalize a bit what we learned from the example with the ship and the soundhouses, two such circles either (1) do not intersect, (2) touch at a single point, (3) touch everywhere, or (4) intersect at two points. Possibility (1) is clearly out, because we have

---

[1] A frequent mistake is to say that GPS operates by triangulation. Trilateration measures the distances related to a triangle; triangulation measures angles. GPS uses trilateration. A triangle is a trilateral, just as a four-sided figure, such as a rectangle, is a quadrilateral.

constructed our diagram so that the circles intersect at "x." Possibility (2) seems unlikely, given the geometry of the situation, and given that the line segments connecting the points with x must not pass through the disk. Possibility (3) is out: the circles would have to have the same centers and radii. We are left then with possibility (4), shown as Figure 2–5: there are two points that are at distance "La" from "a" and "Lb" from "b." One of these is "x." The other is a long way from the disk, is therefore uninteresting (we'll call it point "u"), and is certainly not "x."

The points "a" and "b," of course, represent two of the GPS satellites at a precise instant of time, and point "x" represents the position of the GPS receiver antenna at that same precise moment. (The 0.1 second that it takes for the signals from the satellites to reach the receiver is compensated for in the design of the system.)

This is fine for two dimensions. What happens when we move to three? From a conceptual point of view, the coin becomes a sphere, "x" resides on the sphere (or very slightly outside it), and we need to add a point (satellite) "c," somewhere else in space (not in the plane formed by "a," "b," and "x") in order to be able to locate the position of "x." The problem we solve here is finding the intersection of three spheres (instead of two circles).

While the process of finding this intersection is more difficult mathematically, and harder to visualize, it turns out, again, that there are only two points, just one of which might reasonably be "x."

You may deduce this as follows. Consider initially the intersection of the surfaces of two spheres. First, forget about the special case possibility that they don't intersect at all (their centers are separated by more than the sum of their radii, or one sphere completely contains the other), and the case in which they touch everywhere (same centers, same radii). Now they must either touch at a single point (unlikely) or intersect forming a circle. So our problem of visualization is reduced to finding the intersection of this circle and the surface of the third sphere. If you again discard some special, inapplicable cases, you see that the intersection can be only two points, where the circle pierces the sphere. Only one of these points can be "x."

In theory, one should need only three satellites to get a good, three-dimensional (3-D) fix. You may recall that when you took the receiver into the field, however, you needed four satellites before the unit would calculate a position. Why? Briefly, the reason has to do with the fact that the clock in a receiver is not nearly as good as
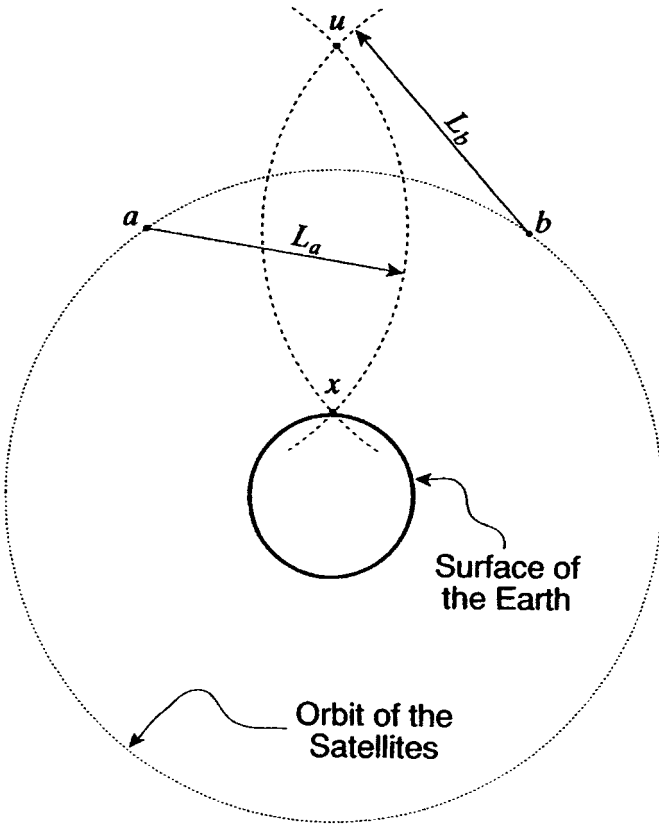
Figure 2–5. Finding "x" by the intersection of circles.

the four $50,000 clocks in each satellite, so the receiver must depend on the satellite clocks to set itself correctly. So, in a sense, the fourth satellite sets the receiver's clock. In actuality, however, all four satellites contribute to finding a point in four-dimensional space.

You now know the theoretical basis for GPS. It is not unlikely that you have several questions. I will defer the answers to a few that we have anticipated so that we can take up an issue that bears more directly on the fieldwork you are about to do.

Factors Affecting When and How to Collect Data

Neither GPS nor any other method can tell you exactly where an object on the earth's surface is. For one thing, an object, no matter how small, cannot be considered to be in exactly one place, if by "place" we mean a zero-dimensional point specified by coordinates. Any object occupies an infinite number of zero-dimensional points. Further, there are always errors in any measuring system or device.

Now that we have thrown out the idea of "exact" location, the issue becomes: what kind of approximation are you willing to accept (and pay for)? There are two philosophies you might consider:

- good enough
- the best that is reasonable

You might use "good enough" when you know for certain what "good enough" is. For example, if you are bringing a ship into a harbor, "good enough" might be locational values guaranteed to keep your ship out of contact with the harbor bottom, or between buoys.

You might, on the other hand, use "the best that is reasonable" when you don't really know what "good enough" is. For example, if you are building a database of city block outlines, you might not be able to foretell the uses to which it might be put. Your immediate needs might suggest that one level of accuracy would be appropriate, but several months later you (or someone else) might want a higher level of accuracy for another use. So it might be worth expending the extra resources to collect data at the highest level of accuracy that your budget and the state of the art will allow.

The major factors that relate to the accuracy of GPS measurements are:

- satellite clock errors
- ephemeris errors (satellite position errors)
- receiver errors
- ionosphere errors (upper atmosphere errors)
- troposphere errors (lower atmosphere errors)
- multipath errors (errors from bounced signals)

There are several 50-cent words above that haven't been defined. We will defer discussion of most of the sources of error until later, primarily because, at the moment, there is little or nothing you can do about them besides knowing of their existence and understanding how they affect your results. In the long run you can do a lot about these errors by a method called "differential correction." But first we will consider an issue called "Dilution of Precision" (DOP) because:

• High (poor) DOP values can magnify the other errors,
• DOP values can be monitored during data collection and the data logger can mask out data with excessive DOP values,
• DOP values, which can be predicted considerably in advance for any given location, can perhaps be reduced by selecting appropriate times to collect data, and
• Differential correction cannot eradicate errors created by inappropriate DOP values.

Position Accuracy and DOP

Prior to the end of 1993, GPS had less than the full complement of 24 satellites operating. In earlier years, there were periods during the day when there were not enough satellites in view from a particular point on the ground to provide a position fix.

Now a data collector can almost always "see" enough satellites to get a position fix. But the quality (accuracy) of that fix is dependent on a number of factors, including

• the number of satellites in view, and
• their geometry, or arrangement, in the sky.

In general, the more satellites in view, the better the accuracy of the calculated position. The GeoExplorer receiver you are using, and many oth ers, use the "best" set of four satellites to calculate a given point—where "best" is based on a DOP value. With more satellites in view, there are more combinations of four to be considered in the contest for "best." Data collection with fewer than five satellites in view is pretty iffy and should be avoided when possible. I'll say more later (in Chapter 7) on how you can know ahead of time when enough satellites are available and what the DOP values will be. It is almost always possible to see four (with

24 up and broadcasting properly—"healthy," as they say) and you might occasionally see more than twice that number.

> The Geo3 is capable of "overdetermined position finding." This means it can use more than four satellites to determine a position. Since a set of four Can determine a position, a set of five could determine five positions—by considering satellites 1234, 1235, 1245, 1345, and 2345. The average of these positions would probably be better than any one alone. The statistical treatment of the use of more than four satellites is a complicated matter and will not be addressed further. Presumably overdetermined position-finding results in a more accurate result.

The concept of DOP involves the positions of the satellites in the sky at the time a given position on the ground is sought. To see why satellite geometry makes a difference, look at the two-dimensional case again shown by Figure 2–6. Suppose first there are two satellites ("a" and "b") that are being used to calculate a position "x": If we know the distances La and Lb exactly, we can exactly find the point "x."

But we don't know La or Lb exactly, because of the error sources listed above. For illustration, suppose that we have an error distance, delta, that must be added and subtracted from each of La and Lb. That is, for each distance there is a range of uncertainty in the distance that amounts to two times delta. This is illustrated graphically by Figure 2–7.

Now suppose there are two satellites ("c" and "d" in Figure 2–8) which are being used to calculate a position "y." These satellites are further apart than "a" and "b," so that the angle their lines make at the receiver are more obtuse than the almost-90° angle from "a" and "b."

If we know the distances Lc and Ld exactly, we can exactly find the point "y." But again we do not know the lengths exactly—we use the same difference of two times delta (in Figure 2–9).

The shaded figure shows the range of positions the receiver might indicate for fix "y." As you can see, the distance between the true position and the position that could be reported by the receiver for the second case is considerably larger than for the first case.

My goal here is to illustrate that **"satellite geometry"** can make a big difference in the quality of the position you calculate. In actual GPS measurements, of course, it is a volume rather than
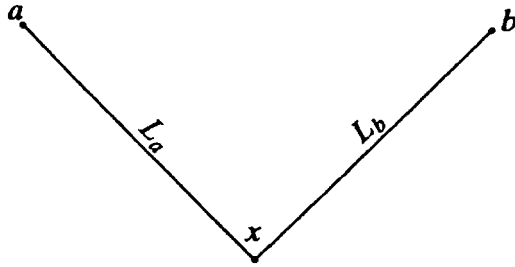
Figure 2–6. Satellite positions relative to "x."
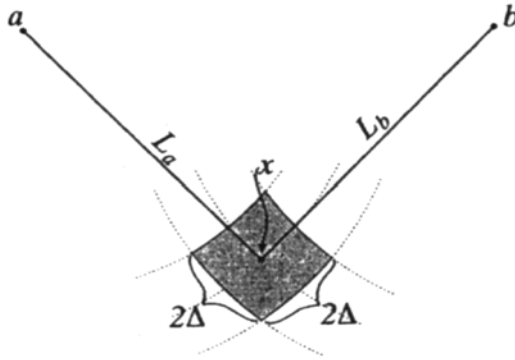
Figure 2–7. Area in which "x" might reside, given satellite positions "a" and "b." The shaded figure indicates the area that contains the actual location sought.
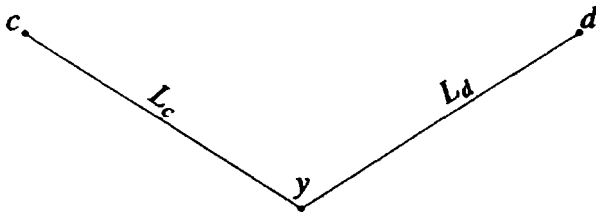
Figure 2–8. Satellite positions relative to "y."

an area that surrounds the point being sought, but the same general principles apply.

So, Actually, What is DOP?

DOP—sometimes referred to as GDOP ('Geometric' Dilution of Precision)—is a number which is a measure of the quality you might expect from a position measurement of the GPS system based solely on the geometric arrangement of the satellites and the
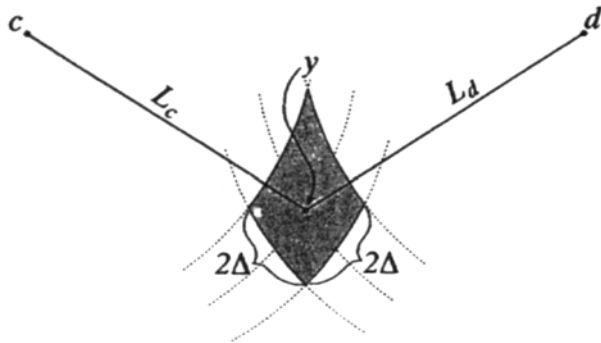
Figure 2–9. Larger area of uncertainty, due to satellite positions "c" and "d."

receiver being used for the measurement. If you think in terms of "geometric strength" you can pretend the electronic ranges from the satellites are cables and you want the strongest arrangement you can have to keep the receiver antenna from moving much when the cables stretch. Ideally you would like to have the four satellites at the vertices of a regular tetrahedron (a three-sided pyramid with all four surfaces equilateral triangles) and the receiver antenna at the center. This would provide the greatest geometric strength, but of course it is impossible for GPS, because three of the satellites would be below the horizon. The best alternative would be when one satellite is directly overhead and the three others are close to the horizon, spaced on a circle, separated from each other by 120°. Simply put, you get the best DOP when the satellites are spread out; the more satellites clump together, the worse the DOP value. In summary, DOP is a measure of the extent to which satellite geometry exacerbates the other errors that may occur in the measurement.

The overall DOP number is made up of several "sub-DOPs":

- HDOP (Horizontal DOP) is a combination of NDOP (North DOP) and EDOP (East DOP),
- VDOP is Vertical DOP,
- PDOP (Position DOP—generally considered the best single indicator of geometric strength) is a combination of HDOP and VDOP (actually the square root of the sum of the squares of HDOP and VDOP),
- TDOP is Time DOP, and
- GDOP ("Geometric" DOP) is a combination of PDOP and TDOP.

You may recall that when you set up the GPS receiver in Chapter 1 you set the maximum allowable PDOP to "06." (Other than the 2-D mask, which you probably won't use, this is the only maximum DOP setting you make.) PDOP is the most important single DOP to consider. As you saw, on one screen you set the PDOP value; on another screen, during data collection, you got a report on the value of PDOP of the constellation the receiver was using. The PDOP mask says: "If the PDOP is too high, then don't record any positions." The recommended PDOP mask value settings are: 1 to 4—great, 5 or 6—okay, 7 or 8—marginal, greater than 8—unacceptable.

STEP-BY-STEP

During the projects in Chapter 1 you visually read and manually recorded, with pencil and paper, positions that were calculated by the GPS receiver. In this session, using the same geographic location as last time, you will use the memory capacity of the receiver to store the readings in machine-readable (i.e., computer-readable) format. Later, you will also take data as you move the antenna along a path by walking, bicycling, or automobile. During both data collection sessions the data will be automatically collected into computer files.

PROJECT 2A

Inside: Planning the GPS Data Collection Session

For the projects in this chapter you will need your notebook, the receiver, and, optionally, the external antenna, if you have it. Set aside a section of the notebook to record information about the files you will collect. On a form, such as the one found at the end of this chapter, you should plan to manually record:

- the date and time,
- a general description of the location or path that is the subject of your data recording,
- the starting time and the ending time of the data collection,
- the file name,

- the amount of memory available in the datalogger before data collection, and then, when finished collecting a file, the actual size of the file,
- the interval between collected data points (e.g., every 10 seconds, or every 50 meters),
- the values of PDOP,
- the number of satellites being tracked,
- the hours of charge remaining in the battery pack, and the amount of time it used during this session.

Setting up the Receiver/Datalogger[2]

Your goal here will be to ensure that the data you collect during your trip to the field will be worth something when you get back.

The receiver obtains data from the satellites and calculates positions at faster than one per second, but the datalogger is usually set by the user to record point fixes in the microcomputer's memory less frequently. You have some control over how often point fixes are recorded. The datalogger also records the exact time each point fix is taken—a fact whose importance will become apparent later.

{__} Be sure that the battery pack is sufficiently charged to complete the session with an ample reserve. You may be able to get an indication of this by looking at how long the receiver has been used since the battery usage number has been reset: hold down the on-off button momentarily and note the number of hours of battery usage since the timer was last reset. Of course this number may be worthless for assessing the charge in the battery if it wasn't reset when the battery was recharged, if a different battery was used by the last person taking data with the unit, or if the unit was powered by an auxiliary power supply as might be found in a car, boat, or airplane. In other words, don't rely solely on the battery usage number when considering the charge left in the battery. When in doubt, recharge.

> The amount of charge (in percentage form) in the internal battery of the Geo3 is displayed on the screen you get with Fn ~ OPTION ~ Status.

{__} Ensure that the receiver settings are proper. First check that the settings correspond to those below. Get to the screen "Main ~

Configuration ~ Rover Options" (As you recall, "Rover" means roving receiver, one that may be moved from place to place.) Scroll this menu until "Dynamics" appears.

{__} Set Dynamics: Land

The LAND/SEA/AIR choice relates to a number of factors affecting both display and internal operations of the receiver.

In the LAND mode the receiver is programmed to cope with **"canopy"** such as trees and heavy precipitation. It is expected that the antenna will be stationary or moving at relatively low velocity (e.g., automobile speed).

In the SEA mode, canopy in the form of precipitation is also expected, as is low overall velocity. But since the antenna might be mounted on a mast which could move rapidly from side to side, the receiver is programmed to expect such movement and disregard it.

In the AIR mode the receiver expects the antenna to be moving fairly quickly and that obstructions to the signal will be minimal. Also, in AIR mode, the display always shows directions in degrees based on magnetic north, rather than true north; pilots navigate on the basis of magnetic north, and runways are numerically designated based on their directions relative to magnetic north.

{__} Set Pos Mode: 3D

{__} Set Elev Mask: 15

{__} Set SNR Mask: 4

{__} Set PDOP Mask: 6

{__} Ignore the PDOP Switch (it is used for 2-D settings only)

{__} Set Antenna Ht: 0.00, or to the height you expect the antenna to be above the point whose 3-D position you are trying to record.

{__} Set Log DOPs: Off

{__} Set Velocity to Off. This option specifies whether the datalogger is to calculate and record the velocity of the receiver antenna. Velocity data use up memory and are particularly unuseful when the antenna is standing still.

{__} For the setting of "File Prefix" ask your instructor or leave it unchanged. (____)

{__} Under the category of "Feature Logging," ignore all settings: "Points," "Line/Area," and "Min Posn." (The GeoExplorer has the

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[2] For purposes of this discussion, we will speak of the receiver as a device that obtains the fixes from the satellites, and a datalogger as a device that records these data into a file. The GeoExplorer equipment you are using houses the receiver and datalogger in the same physical unit.

capability of recording attributes of features (e.g., lampposts), but we won't be using that ability until the exercises in Chapter 7.)

{__} *Set the "Not in Feature Rate":* The datalogger usually does not record all the points the receiver calculates. Which points are actually recorded? Basically, you can set it to record points under one of two circumstances:

- when a certain interval of time has elapsed since the last point was recorded, or
- when the receiver senses that the antenna has moved at least a certain distance from the last point recorded.

To experiment with this setting, press "CMD" when the highlight is over the number. On the screen that appears, you may, with the left-right arrow keys, select either of two fields.

The left field may be set to any integer value from 1 to 999, or to "All" or to "Off." (By continually pressing an up-down arrow key, you may scroll through a sequence of numbers; also, individual digits are addressable by use of the left- and right-arrow keys.)

The right field may be set to "seconds," "meters," or "feet."

Since in this exercise you will not be moving the antenna once datalogging starts, set the interval designation units to seconds. Set the number to three (3) and press "CMD."

> To set the "not in feature rate" on the Geo3: Fn & OPTION ~ Setup ~ Configurations ~ Data ~ Log between features.

{__} Double-check that the "Not in Feature Rate" is set to three seconds.

{__} Under the category "High Accuracy" ignore all settings except "Recording." Make sure it says off.[3]

{__} Now you should have scrolled back to "Dynamics," which is where you came in. "Esc." "Esc."

{__} From the Main Menu, select "1. Data Capture."

You probably now have the following six options:

{__} Select "Open Rov. File" to open a rover file. The datalogger would begin recording data if the unit were outside and exposed to enough satellites that met the configuration requirements.

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[3] The GeoExplorer, in high accuracy mode, can find locations within centimeters. This, however, is a much more involved procedure.

- Data Capture -
1.Open Rov. File
2.Open Base File
3.Review File
4.Delete File
5.Rename File
6.Dictionary

The data capture screen is transformed; it now looks something like this:

R112420A   0
1.File Status
2.Pause
3.Close File
4.Main Menu

The field to the left on the top line is the name of the file the receiver would use if it were outside so it could begin collecting data.[4] (Since the antenna is shielded from satellites, the file will be initiated but no data will be recorded.) The file name consists of eight characters:

ummddhhi

Separated for better readability, it looks like this:

u mm dd hh i

The initial character ("u" for user) of the file name is user-selectable. It is set under "Rover Options." Your instructor may have set it so he or she can keep track of collected student files.

The middle six characters hint at the date and time: the first two digits (mm) are the month, the next two (dd) the day, and the final two (hh) the hour in UTC time. (The year the file is collected is not reflected in the file name, but it is recorded, along with many other parameters, in the file itself.)

The final character ("i" for index) is one of the 36 character sequence "A, B, C,…Z, 0, 1…9." Prior to recording the first file of a

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[4] This is a "default" file name. You may change this name in the GeoExplorer if you wish. I suggest you leave it as it is. If you want a different name, wait until the file is transferred to a computer.

given hour, the "i" character is set to "A" by the receiver at the beginning of the hour. It is "incremented" to the next character in the sequence each time a file is collected and starting during that hour. This allows several files (up to 36 with the same "u" character) to be collected during a single hour, each with a unique name. If a file is open as the hour changes **the file name does notchange**. Data collection continues under the same file name. A given file may contain data taken over a several-hour span.

{__} Check the file name displayed, to be certain it corresponds to the default discussed above, in terms of time and date. Record its name on a piece of scrap paper, since you will want to erase it shortly and you want to be sure you have the right one.

Before opening a file on the Geo3, set the datalogger so it beeps every time it takes a fix. This is the only way to know easily that it is collecting data. To set the "Beep volume" on: Fn & OPTION ~ Setup ~ Configurations ~ Other ~ Beep volume ~ On. Then CLOSE ~ CLOSE ~ CLOSE.

To open a file on the Geo3: Fn ~ OPTION ~ File. At this point you will see the possibility to "Create new file"; select that with the arrow keys if necessary. Before you press ENTER look below the two option boxes and find the file name. Confirm to yourself that it conforms to the description of file names given above in terms of date and time. Now press ENTER **once** only. You might think that you would press ENTER again, if you want to take data "Now" but that will tell the datalogger to start taking data for a Point, Line, or Area feature and you don't want to do that.

Although it looks like nothing is happening, the receiver is feeding "Not in Feature" position data to the datalogger **IF** it sees enough satellites that meet the requirements. You will hear a beep from the unit when fixes are recorded. Of course, right now you are inside so no data will be collected.

{__} Note the number to the right of the file name. It is the number of data points collected. The number will be zero unless the antenna is outside and some data have been collected.

The menu items suggest that you may inquire as to the status of the file, suspend the data collection process, close the file, or return to the main menu.

{__} Scroll along the menu until "File Status" is highlighted. Press "CMD." Scroll this menu until the name of the file appears at the top. The information portrayed should look something like this:

- File Status -
File: R112120A
Size 0.7519K
Free 188.82K
#Features 0
#Positions 0

So you have the file name, the number of fixes (points) in the file, and file size (in **k,** meaning **kilobytes**).[5] Also on this screen the item "Free:" indicates the amount of memory space remaining in the datalogger. Depending on what else is stored in the memory, this number can be anywhere from about 200,000 characters (or **"bytes"**) to none at all. When you want to know how much memory is left in the datalogger this is one way to see it.

Another designation is the "Size:" of the file currently being collected. A single 3-D fix, with no velocity or DOP information recorded, requires 20 to 25 bytes under the best circumstances. Under less than ideal conditions (e.g., interference with the satellite signals—by buildings and trees—which causes the receiver to switch constellations), each point may occupy an average of 100 bytes, more or less. Note that even though no "Positions" have been recorded in this file, it still uses up memory.

{__} How much "Free" memory remains in the datalogger? _____. About how many position fixes could you store in that amount of memory under the best of conditions? _____ About how many under poor conditions? _____

{__} "Pause" the data recording process. "Resume" it.

{__} Close the file.

{__} ***Review the file:*** If there are several files in the memory you may scroll through them. They are numbered in the order that they were formed. The one you just "collected" should be the last. Check the name you wrote down on the scrap of paper. Several items of information are available through this file menu. For example, a file might look like:

{__} Move to the file you just opened—which will show zero positions. Delete the file. (Be careful to delete only the file you

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[5] A kilobyte is 1024 bytes, or characters, of information. A character is a letter, digit, or special symbol. This page in this textbook represents approximately two kilobytes.

Review: A010203A
Rover File
Log Rate: 10sec
Positions: 180
Features 0
Size: 7.055K
Duration: 1:05

created. It will be the one with the highest sequence number; also check that it was made today ("today" in Greenwich, that is).

{__} Run through the Checklist in Chapter 1 in preparation for going into the field.

{__} Turn off the receiver.

In the Field: Collecting Data

{__} Turn on the receiver.

{__} Return to the site of your first data collection effort (PROJECT 1B), where you wrote down position fixes on paper. Once you have considered the factors you previously learned about, regarding good data collection:

{__} Position the antenna where it was before,

{__} Wait until the receiver is locked onto enough satellites,

{__} Make the appropriate notes on the data collection parameter form found at the end of this chapter, and

{__} *Begin recording data:* On the main menu select "1. Data Capture." Then select "1. Open Rov. File." Be very careful that you don't open a base file. Very unfortunate things happen if you get this one wrong. ("Open Base File" is the option used when the receiver serves as a nonmoving station to collect data that may later be used to correct the data obtained by roving stations. Among other concerns, when a base file is collected, the receiver records data from all the satellites in view, not just the four at a time used for normal, 3-D fixes, and that uses up memory at a great rate.)

> Begin collecting data with the Geo3 as described above. Be sure the Beep volume is on.

It has been suggested that about 180 fixes, if taken over a period of several minutes, are statistically sufficient to achieve a reasonable

level of accuracy—given the quality of your receiver and the situation.

Recall that you set the datalogger to record a point every three seconds, so nine minutes should suffice for the data collection effort. If you have not collected the correct number of points in that length of time it is perhaps because, at times, the receiver lost lock on enough satellites. The reasons for this vary widely, but a principal one is that someone or something is getting in the way of a signal. The datalogger will record a fix only if DOP requirements, signal-strength requirements, number-of-satellite requirements, and so on, are met.

{__} While data are being recorded, take time to flip to some other screens; **data recording will continue unimpeded**. You can look at File Status and GPS Status. You may change such settings as datum, time display, units, and so on. Recording will continue (provided you keep your head out of the way of the satellite signals).

Important fact: It does not matter what display settings you use fordatum and units; the display has no effect on what is recorded in thedatalogger memory. Point fixes will be stored in latitude, longitude, andmeters above the reference ellipsoid. The lat-lon numbers will be basedon the WGS84 datum.

{__} Write in your logbook, on a copy of the form provided, the relevant information about this file.

{__} After nine minutes, verify that you have approximately 180 fixes. If not, figure out why. If you are well short of the target number of fixes, consider running the data collection part of the experiment again. Perhaps raising the PDOP to eight (8) will help, although it may slightly degrade the quality of the data you get.

{__} Close the file. Review it. Finish writing in your log. Assuming everything went according to plan, turn off the receiver.

{__} At this point you may either go on to Project 2C, in which you upload the data you have collected into a PC, or you may collect additional data in Project 2B.

PROJECT 2B

Taking Data Along a Path

In this project you will again use the receiver to take fixes and record the coordinates in the datalogger. The difference between

this and the previous project (2A) is that you will move the receiver antenna through space in order to record data points along a track. This capability allows you to generate the more interesting features of a GIS: arcs and polygons, rather than simply points.

You may select one of three ways to move the antenna: by foot, bicycle, or automobile. Read the sections below to decide how you want to take data. (In the event that you cannot take moving data, several data files are provided on the CD-ROM that accompanies this book, so you may process those files. Files found there include those taken by automobile, bicycle, airplane, helicopter, sailplane, cruise ship, and sailboat. I have no data presently from a hot air balloon; if you generate some, please feel free to send it in.)

Generating a series of points while moving provides some challenges.

- Accuracy. We indicated that 180 fixes at a single location provided a reasonable approximation of the position of the antenna. In collecting data while moving, of course, you will collect only one fix at each location, with the concomitant loss of accuracy.
- Constellation Vacillation. When you set up the receiver at a single point, you can try to optimize the view of the satellites by staying away from obstructions. While moving, you have little opportunity to pick the points at which the receiver calculates a position. As the antenna moves along the path to different positions, the receiver, by simply trying to pick the best set of four satellites to calculate positions, may choose different constellations of four satellites, due to signal obstruction caused by tree canopy, buildings, overpasses, or tunnels. Because of the various errors, which are different from satellite to satellite, a position fix reported by the receiver using a new constellation may be different from where it would have been had the previous constellation been retained. Thus, the position fixes may not follow a clean line, but may jump from side to side of the true path. A second consideration in taking data along a path is that each change in constellation increases the amount of memory necessary to store data.
- Multipath. Substantial errors may occur if a given radio signal follows two paths to the receiver antenna. This can happen if a part of the signal is bounced off an object, such as a building. The arrival of two or more parts of the signal at different times

can confuse the receiver and produce a false reading. (You may have seen the results of multipath on the screen of a television set receiving signals from an antenna [not from cable]; it appears as "ghosting"—a doubling or tripling of an image.) Many GPS receivers are programmed to disregard the second signal. But a problem can occur if the direct signal is blocked but the related bounced signal is seen by the antenna and recorded.

Taking Data on Foot

While walking, you need to be careful to keep the antenna high enough so that no part of your body impedes the signal. With the first version of the GeoExplorer, this means holding it high, well out in front of you, so that the internal antenna can have a clear "view" of the sky. With the GeoExplorer II with the external antenna, it is probably also a good idea not to wave the antenna around any more than is absolutely necessary. A pole, with the unit or antenna affixed to it, attached to a backpack is a nice solution.

Set the interval between logged points based on time, not distance, although you might think that taking a point every so many feet or meters would seem like a good idea. The problem is that the receiver will record almost all spurious points that occur, because it is set to record a point that is more than "d" distance away from the last point. If "d" is, say, set to 20 feet, and errors creates a point 25 feet away from the last point, this spurious point will be recorded. (Recall that the receiver actually generates points at more than one per second.) If, instead, you are recording points, say, every four seconds, then there is a better chance that a spurious point may be ignored. You may certainly try this both ways, but you will probably get a ragged path with many spikes in it by using distance as the logging interval while walking.

A brisk walking speed is about five feet per second, so you can set the time interval accordingly, depending on the point spacing you want. For this project, if you are walking, select a path, preferably closed, of a mile or two.

Collecting Data by Bicycle

An economical way to collect data over significant distances along a linear path is to use a bicycle. But there are a number of pitfalls,

in addition to the general dangers all bicyclists face, mostly from automobiles. The principal problem relates to the line-of-sight requirement: unless the antenna is positioned far away from your body, or above it, the receiver will consistently lose its lock on one satellite or another.

One solution—not recommended—is to attach the antenna to the highest point on the "you+bicycle" combination, but bicycle helmets are pretty nerdy-looking appliances anyway; when you duct-tape a GPS antenna to the top of it the effect is, well, startling —to the point that neighbors come out with cameras to capture the image. One solution is to "shoot the moon" as it were, to give up any pretense of self-respect, and clothe the antenna in one of those "propeller beanies."

Some other solutions:

- have a special bracket made for a surveying pole with the antenna affixed,
- wear a backpack containing the receiver with the antenna on a pole
- ride a tandem bike (a bicycle built for two), and attach the antenna to the second seat. The effect is still pretty ridiculous but let's face it: you aren't going to collect GPS data on a bicycle while maintaining a significant level of dignity anyway.

Collecting Data by Automobile

To collect data by automobile you should ideally use the remote antenna, available for the GeoExplorer II, with a magnetic mount. Place the antenna on top of the car and run the antenna lead through a window, preferably in a rear door. Some safety tips:[6]

- Put a thin pad of cloth between the magnetic mount and the car roof to prevent scratching the car's finish.
- If you want to roll up the car's window be careful not to crimp the antenna wire between the glass and the frame; this is especially easy to do with power windows.
- Do not open the door through which the antenna lead is threaded.
- Leave enough slack in the antenna lead outside the window so that when you *do* accidentally open the "antenna lead" door you don't drag the antenna across the roof.

If you are not using a remote antenna, place the GeoExplorer as far forward on the dashboard, under the windshield, as you can, so that metal of the car's roof blocks signals as little as possible.

One advantage to collecting data by car is that you can use the power supply from the vehicle. *However, remember not to start or stop the enginewith the receiver attached to the car's power supply.* The proper order of events is:

1. Start the car engine,
2. Connect the plug to the car's auxiliary power (cigarette lighter) receptacle,
3. Turn on the receiver,
4. When you are ready, start recording data.

When you are through, **undo** the steps above, *inreverseorder*.

With automobile data collection, you may use either time or distance as the logging interval. While errors may still be a problem, the distance you set between logged points is going to be much greater with the car than while walking. Thus, the chance of a point being generated by a multipath event that is greater than the logging interval is reduced considerably.

While riding as a **passenger** in the auto (the driver is supposed to keep eyes on the road) examine the navigation screen occasionally. You will notice that it gives the car's speed within a mile per hour or so, and the direction as well. (You may set the units of display so as to get miles per hour; changing units will not affect data collection, although pulling the receiver back from its place at the front of the dash may.)

Actual Data Collection

{__} Fill out the initial portions of the Data Collection Parameter Sheet.

　{__} Choose a method of transporting the antenna.

　{__} Choose a route—perhaps a closed loop.

　{__} Check and set the parameters under "Configuration ~ Rover Options."

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[6] The reader could speculate on how the author can be so detailed in his description of the problems that might arise, but the time would be better spent learning about GPS.

{__} Decide on a recording interval.
{__} Start the data recording process.
{__} Take a minimum of 200 points.
{__} Stop recording data.
{__} Complete the Data Collection Parameter Form.
{__} Shut off the receiver.

PROJECT 2C

Back Inside

{__} If you have not already done so, finish filling out the data collection parameter sheet(s) for the PROJECT 2A (and 2B) data collection session(s).

{__} Compare the memory used and the number of fixes collected. How many bytes did the average fix require? _____. If this is much larger than 25 then it may be that the unit had to repeatedly change constellations, and hence store more data, to maintain the set of four satellites with the best PDOP. While any extended data collection session will involve constellation changes—after all, each satellite is only visible from a given point of the earth for a few hours a day—you will get the best data if you are careful not to force constellation changes by obstructing the signals.

With the Geo3 you can get some information about the files you just took by: Fn & OPTION ~ File ~ OPTION ~ File info. Then select the file you want infomation about with the up and down arrow keys. Here you are told about the number of positions in files, but not their size. If you want to know the file size you can use the Delete menu item rather than File info. Don't hit ENTER. You needn't delete the file to have a look at it. Use CLOSE.

At this point you have recorded spatial data, but it is essentially locked away in the datalogger. Copying it from the datalogger into a personal computer (PC) is the next undertaking. This process is sometimes called **uploading data**.

{__} The first step in transferring data is to make a physical connection between the receiver/datalogger and the PC. Your instructor will have paved the way for this. Probably all you will have to do is connect the datalogger to a cable with a round plug, the other end of which is connected to the computer.[7] It is very important that you use care in connecting the cable. First, be

careful that you merely open the rubber grommet assembly on the back of the GeoExplorer; don't pull the whole assembly out of the unit. Second, the cable will fit into the GeoExplorer plug in only one way—unless you force it, in which case you can bend the delicate pins on the cable plug. Hold the unit with your left hand, out in front of you, **top** side **up,** with the ***back*** facing you. Take the cable in your right hand and, with the cord going off to your right, make the connection. The proper configuration is with the **plug on the left side of the unit** and the cable stretching **horizontally across the back of the unit, to the right**.

> Connecting the Geo3 to a computer can be done in a couple of ways. The simplest is to connect the cradle that came with the Geo3 to both the computer and an AC power supply. Probably this will have been done for you. All that remains is to put the Geo3 in the cradle and turn it on.

Execute the Pathfinder Office Software

{__} ***Start the Pathfinder Office Software:*** I'm assuming that you have a passing familiarity with Windows 95, Windows 98, Windows NT, Windows 2000, or their successors. If not, a crash course or some tutoring is in order. Your instructor will have given you some directions on how to log onto the computer you will use and to invoke Pathfinder Office. Follow those directions now.

{__} If a Select Project window came up when Pathfinder Office started, dismiss it (by clicking the "X" in the upper right of that window). The results should look something like Figure 2–10, perhaps missing a toolbar or two; we'll fix that. If the Pathfinder Office window does not occupy the full screen, double-click on its title bar.

"Project" is one of those annoying English words that subsume two distinctly different pronunciations and meanings under a single spelling.[8] As a verb, it can mean, for example, shine light through film onto a screen, or "project" a piece of the Earth's surface to make a map—that is, make a geographic "projection." But "project," as a noun, can mean a focus of activity, time, data, money, and so on, so as to accomplish some goal, as in to "launch a

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[7] People have different attitudes about plugging devices into computers. Some feel it is inconsequential whether or not the computer is turned on as long as one is careful to orient
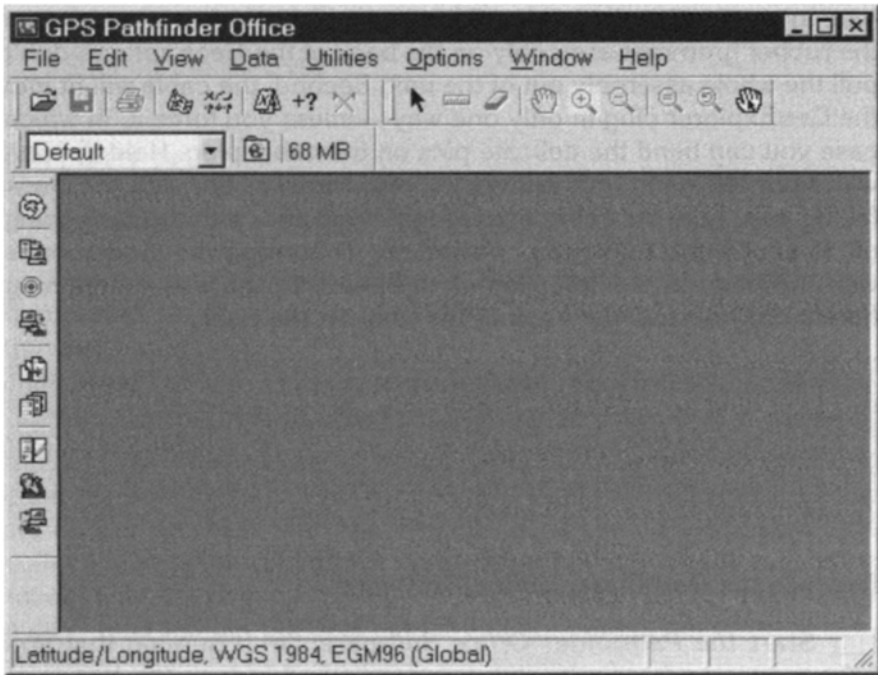
Figure 2–10. The main window of GPS Pathfinder Office.

project." In the case of Pathfinder Office, it means the latter, although, since the subject in general is geographic data, no one could complain had you guessed otherwise. In any event, the function of the "Project" is to serve as a closet for the files you will work with.

A Project in Pathfinder Office has several components. First is the Project Name. This name points to a primary folder (preferably with the same name, but that is not required). The primary folder usually contains data files plus three subfolders, named backup, base, and export.

{__} ***Make a new Project with its associated folders:*** In the File menu click Projects. (From now on I may indicate a sequence

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the plug properly and not let mismatched pins make contact. Others feel that power to the machine must be turned off to assure that no damage results from making the connection. Please consult with your instructor to see what the policy of your lab is.

[8] Half a heteronym, perhaps.
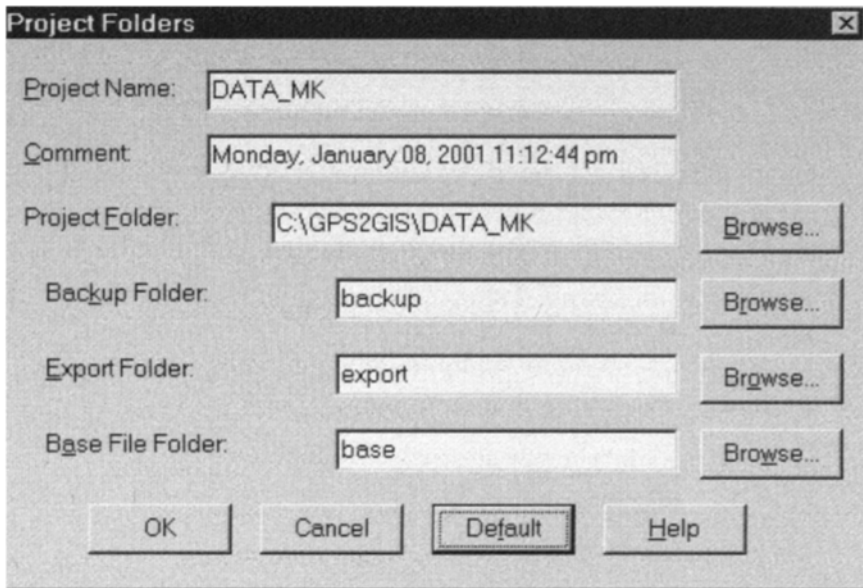
Figure 2–11. Setting up the Project and its folders.

of actions like this by File ~ Projects.) Click "New" in the Select Project window. A "Project Folders" window will appear. You will make a project with the name DATA_yis, where **"yis"** indicates **Y**our **I**nitial**S** (in capital letters, up to three). For example: DATA_MK. The project is to be located in a folder named DATA_yis, which will be under the folder X:\GPS2GIS, where "X" is "C," "D," "E" or whatever hard disk drive your instructor tells you the GPS2GIS folder is located on. Type

DATA_yis

in the Project Name field. Type

__:\GPS2GIS\DATA_yis[9]

in the Project Folder field. This procedure assures that the Project Name and the primary project folder window will be identically designated—which is good practice, but not required. See Figure 2–11.

If you click OK the window will disappear and the Select Project window will again become active.

{__} Examine the Select Project window. It should look about like Figure 2–12. If it does, okay the window. You have now set up Pathfinder Office so it will install your files in the proper places.
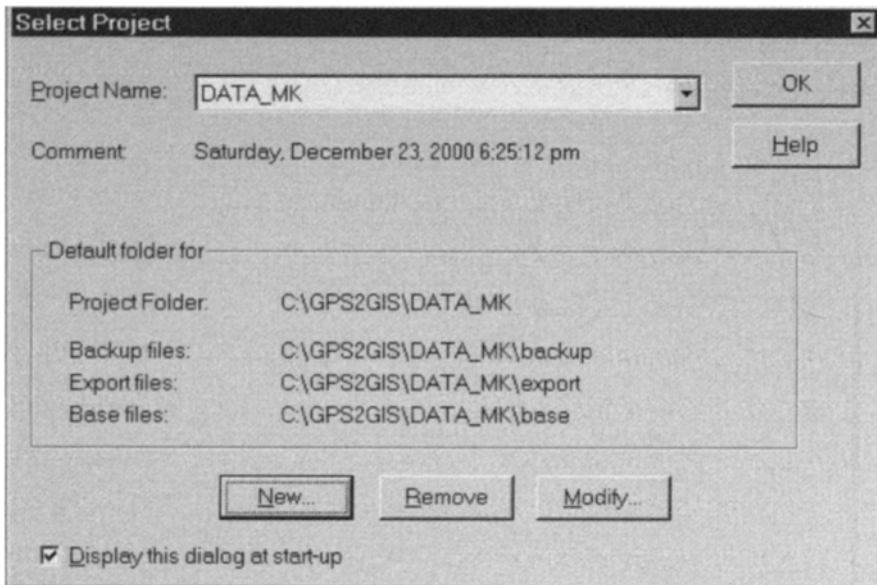
Figure 2–12. Selecting a Project.

You have established a main folder for your data, and three sub-folders under it for functions that will be explained later.

{__} Select Options ~ Toolbars to make sure that checks appear next to all toolbar selections: Standard, Project, Mouse, and Utility. Also make sure a check appears next to the Status Bar menu item.

{__} Check that the Project name appears on the Project toolbar. Also on this toolbar will be the amount of disk space remaining on the associated disk drive. You should also see a folder icon. Click on it. You will see the contents of the folder for the project. It will contain three folders: backup, base, and export. Dismiss the project folder.

To transfer data from one device to another, they have to speak in the same dialect, as it were. This means the communication parameters on each device must be set to the same values. A common protocol is called XMODEM. A commonly used rate of transfer is 9600 bits per second (called **"baud"**[10]) which results in about 1200 bytes, or characters per second.[11] Parameters of Parity,

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[9] Place in the blank whatever hard drive disk identifier your instructor tells you is correct.

- Comm Port A -
1.Protocol XMDM
2.Baud 9600
3.Parity None
4.Data Bits 8
5.Stop Bits 1

Data Bits, and Stop Bits relate to the configuration of bits in each byte sent.

{__} *Set the communication parameters in the GeoExplorer:* Turn on the GeoExplorer Receiver/Datalogger. Pick "Configuration ~ Com munication ~ Port A." The screen will probably appear as shown below. If not, change the parameters so it does, unless your instructor has indicated otherwise.

Probably your PC has been configured to accept data in this form. The local convention may be different, however. If things don't seem to be working, check with your instructor.

{__} From the main menu on the receiver, select "7. Data Transfer." The receiver should tell you that "Comm is Idle."

> To set the communication parameters on the Geo3, pick up the unit from the cradle and simply: Fn & OPTION ~ Setup ~ Configurations ~ COMMS ~ Enter. For Data transfer choose "Support module." Skip over RCTM input and NMEA output. Set the Port settings to those shown above for the GeoExplorer. Press CLOSE a couple of times. Return the Geo3 to the cradle.

{__} *Prepare to ship the files you collected to the PC:* In Pathfinder Office select Utilities, then Data Transfer.[12] Shortly a Data Transfer window should appear, as in Figure 2–13.

The Device field in the upper left should confirm that you are connected to a GIS datalogger; the port name should be given. On the right side of the window it will indicate the type of device, e.g. GeoExplorer or Geo3. The Receive and Send buttons refer to the primary direction of dataflow. In this case you want the PC to

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[10] You could think of "baud" as "bits audio," since it first referred to the speed of transmitting data across voice telephone lines.

[11] Or a little less. A byte is 8 bits, so if only bytes were transferred the rate would be 1200 bytes per second. But there are other bits transmitted for handshaking, redundancy, checking, parity, and so on.
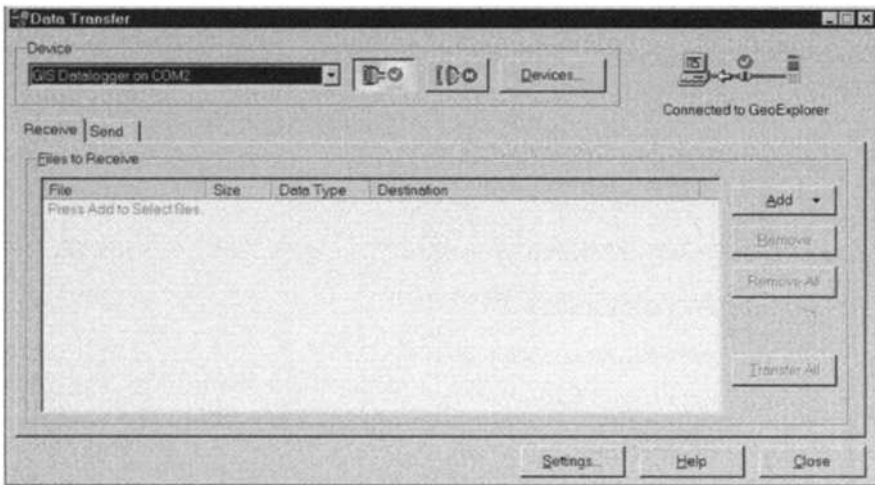
Figure 2–13. Connection to GeoExplorer prior to file transfer.

receive data. If you press the Settings button you can (1) say whether you should be told if you are about to overwrite a file already on the computer (you should), (2) whether you want backup copies of the files made on the PC (yes), and (3) whether the files on your GeoExplorer or Geo3 should be deleted after they are transferred (not a good idea).

{__} Press the "Add" button and pick Data File. An "Open" window will appear; within it you will see the list of data files that reside within the datalogger. Please see Figure 2–14. Move your mouse cursor over the buttons on the upper right of the window. Press the one that says "Details." Depending on the datalogger you will get different amounts of information.

{__} Select, by clicking with the mouse on the file name, one of the files you want to add to the Data Transfer window. If you want more than one file added, hold down the Shift key and click on the other file names. (If you need to start over in selecting files, click in a blank area of the window.) Examine the Destination field to make certain the files are going where you want them to. Click

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[12] The procedure described here is for Pathfinder Office 2.70 and later versions. If you are using version 2.51 or an earlier version the procedure will be different, but obvious. If you should have trouble, the earlier procedure is available as a text file on the CD-ROM accompanying the book.
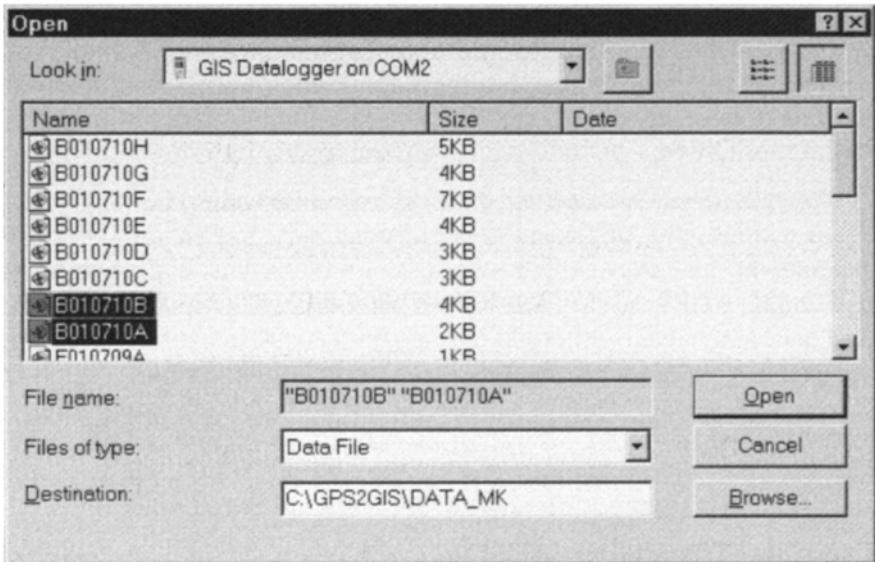
Figure 2–14. Transferring files from the GeoExplorer to the PC.

Open. The "Open" window will disappear and the files you selected will appear in the Data Transfer window.

{__} Pick up the datalogger [unless it is a Geo3 in the cradle] and hold it so that you can see both it and the PC screen. Press the "Transfer All" button and observe. The datalogger will indicate that it is sending a file (the bar graph will decrease); the PC will show a window (Receiving) indicating that a file is being received (its bar graph will increase). This may all go by pretty fast for small files. (If the process should stop because of a communication error, just press the Transfer All button again. The transfer should proceed from where it halted.)

{__} After the transfer stops you can ask for More Details. Read, then dismiss that window. Click Close on the Transfer Completed window.

{__} While the Data Transfer window is still open, repeat the process. Note the warning you get about overwriting files. You can do this as many times as you want to get the feel for how to transfer data.) When through, click Close on the Data Transfer window.

{__} On the Project Toolbar is a folder icon with a blue-green logo. When you press it, up will come a window with the main project folder: __:\GPS2GIS\DATA_yis. Note that your files, with the

extension "SSF"[13]—meaning standard storage format—are located in that folder. There is also a "Log" file giving the details of the transfer. Note also the three subdirectories or folders in __: \GPS2GIS\DATA_yis. Both the export and the base folders will be empty, but if you double-click the backup folder you will see that it contains not only copies of the SSF files you just transferred, but also RAW (raw data) files that constitute intermediate steps in the construction of the SSF files. You may never need these files, but then again you might—long after the data have been cleared out of the receiver. Dismiss the window. Exit Pathfinder Office.

You have finished collecting data and have stored it on a PC. In Chapter 3 you will examine, and map, these and other data. In Chapter 4 you will experiment with ways to improve the accuracy of the data. In Chapter 5 you will combine GPS data with data from other sources using Arc View GIS. And in Chapter 6 you will export the data from Pathfinder Office to formats acceptable to ArcView and ArcInfo.

{__} Before you disconnect the GeoExplorer from the PC, do Exercise 2–1.

Exercise—Transfer the Almanac

Exercise 2.1: A NAVSTAR almanac provides a description of approximately where the satellites are at any given moment in time. Collected by and retained in the GPS receiver, the almanac tells the receiver which satellites it will be able to see during a data collection session. That is, the almanac helps in the initial phases of outdoor data collection. So the receiver automatically collects an almanac every time it is turned on, if it can. To collect an almanac, the receiver needs to be picking up the signal from at least one satellite for about 15 minutes. Almanacs are available from the satellites, all day, every day, and usually have validity for up to three months. Of course, if a new satellite is put up, or the existing ones are rearranged in their orbits, the almanac becomes less useful immediately.

The almanac may be copied from the receiver to the PC using Pathfinder Office. Having an almanac on the PC is not necessary in order to use the data you have collected, but later you will see

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[13] Depending on how Windows is set up, the extension "ssf" may or may not show in the folder.

that it is useful for planning a data collection session. For example, when used with a Pathfinder Office module called QuickPlan, it can tell you how many satellites are available at any time during the day, and what DOP values you can expect. Furthermore, copying an almanac to the PC is illustrative of the communication process, so we do it for practice.

{__} With the GeoExplorer still connected, restart Pathfinder Office. Using the knowledge you gained from transferring files, set up Pathfinder Office to transfer the almanac to your PC. You will use the data type "Almanac." The path and Output File will appear by default as

C:\Program   Files\Common   Files\TrimbIe\Almanacs \Almanac.ssf.[14]

Change the Almanac name to Almanac_yis and store it in __: \GPS2GIS\DATA_yis. (You can store the almanac on the PC by any name and in any place. However, unless told otherwise, QuickPlan will look for the latest almanac with the name "Almanac" in the default location.) When you press Transfer All the GeoExplorer and Pathfinder Office will both correctly claim that the almanac is being transferred.

{__} When the transfer is done, close the Data Transfer window and exit Pathfinder Office. Turn off the GeoExplorer, disconnect it from the battery or other power source, and **carefully** disconnect the upload cable.

You have completed uploading your data files and the current almanac. (You were asked to put the almanac in your own folder since others might want to use the "official" almanac in

C:\Program   Files\Common   Files\Trimble\Almanacs \Almanac.ssf,

which might have been collected at a later time.) In the next chapter you look at several sample data files with Pathfinder office, and then at your own files.

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[14] "Program Files" and "Common Files" are both folder names. In what this author considers a significant design error, Microsoft Windows allows blanks to be present within folder and file names.

Data Collection Parameter Form—GPS2GIS

Memory Remaining in the Datalogger _____K

Hours of Battery Use Prior to this Data Collection _____:_____

Location _____

_____

_____

Date _____ Day _____

File name _____

Time: Start _____

Using SVs (initially): _____ _____ _____ _____

PDOP _____ (HDOP _____ VDOP _____ TDOP _____)

                    (The GeoExplorer displays only PDOP)

Position Logging Interval: 1 fix per _____ (number) _____ (units)

Total Number of Fixes _____

Time: Stop _____ Duration _____

Using SVs (at end): _____ _____ _____ _____

PDOP _____ (HDOP _____ VDOP _____ TDOP _____)

File Size (in K) _____. File Size (in Bytes: K*1024)
_____Bytes

Bytes per Fix (Number of bytes divided by number of fixes)

_____

Memory Remaining in the Datalogger _____K

Hours of Battery Use _____:_____

Notes: _____

_____

_____

_____

_____

3
Examining GPS Data

IN WHICH we continue our discussion of the theoretical frameworkof GPS position finding, and you practice using PC software toinvestigate files collected by GPS receivers.

OVERVIEW

Some Questions Answered

As you read the last two chapters some questions may have occurred to you. And the answers to these questions may generate other questions. Here are some that come up frequently:

Question #1: "The captain of the ship of Figure 2–1 had a map showing the locations of the soundhouses. But how does the GPS receiver know where the satellites are?"

A map is a two-dimensional scale model of the surface of the Earth. But models can take many forms, including mathematical. Due to the nature of nature, as elucidated by Isaac Newton and Johannes Kepler, the position of a satellite at any time may be predicted with a high degree of accuracy by a few mathematical equations. A satellite orbiting the earth may be modeled by formulas contained in the memory of the microcomputer in the receiver. When the formulas are applied to bodies at the high altitudes of the GPS satellites, where they are free from atmospheric drag, the formulas are relatively simple and can predict the position of the satellite quite accurately.

Almost all formulas have a general form, into which specific numbers are "loaded." For example, in an equation of the form

$$Ax + By = z$$

A and B are **parameters** which represent constant numbers that may be inserted in the equation. When A and B are replaced by actual numbers, then the equation is only true for certain values of x, y, and z. The receiver carries the general form of the formulas that give the position of each satellite. Before the range readings are taken by the receiver, the satellites will have broadcast the values of their particular parameters so the receiver can complete its equations. Then, by knowing the current time at a given moment (the moment at which the distance reading is taken), the receiver can know where the satellites are.

Actually, the satellite message coming to the receiver antenna is in many parts. Two of these might be called the almanac and the ephemeris data. **Almanac** information is broadcast to provide close, but not precise, satellite position information. The almanac for all satellites is broadcast from each satellite. Furthermore, each satellite broadcasts **ephemeris** information (which applies to that satellite only), that provides up-to-the-minute corrections. The satellites are not completely predictable in their orbits because of such forces as gravitational pull from the sun and moon, the solar wind, and various other small factors. Therefore the satellites are carefully monitored by ground stations and told their positions; each satellite then rebroadcasts this information to GPS receivers.

Question #2: "The captain needed to know exactly what time it was in order to determine his distance from the soundhouse. How is the clock in the receiver kept accurately on GPS time?"[1]

The short answer is that the receiver clock is reset to GPS time by the satellites each time a position is found. Such resetting is necessary because, while the receiver clock is very consistent over short periods of time, it tends to drift over longer periods. (Each of the four atomic clocks in each satellite costs about $50,000; the single clock in the receiver obviously costs a whole lot less, so you can't expect the same sort of accuracy. If you don't use the receiver for a week or two, you may notice a difference of several seconds between the time the receiver displays and true time.) The clocks in the satellites keep time to about a tenth of a billionth of a second (a tenth of a nanosecond).

If you consider "time"[2] as the 4th dimension and accept that it takes one satellite to fix each dimension, then it is clear that four satellites, working in concert, can set the clock and provide a 3-D spatial position.

Recalling our discussion of the theory of GPS and from the geometry of the diagrams you examined, you might presume that

only three satellites are required for a 3-D fix. But given that the receiver has only an approximate idea of what time it is, what must be calculated is a 4-D fix. So four satellites are required. It is not correct to say that three satellites are used for the 3-D fix and the fourth sets the receiver clock. Rather, all of the satellites operate in concert to find the true "position" of a receiver antenna that may move in space (relative to the earth) and does move in time.

(GPS, as previously mentioned, has had a revolutionizing effect on the business of keeping extremely accurate time—to better than a billionth of a second. While most of those who use GPS are concerned with finding positions, the system also supplies extremely accurate time signals to receivers whose positions are known with high precision. GPS has made it possible to synchronize clocks around the world. This has made it possible, among other things, to gain knowledge about the makeup of the earth's center. Since seismologists throughout the world know the exact time, they can track the shock waves from earthquakes as they pass through the earth. Another use of the ability of GPS to synchronize clocks around the world is in routing Internet (worldwide web) traffic. It would not have been unreasonable to have called GPS by the acronym GPTS: the Global Positioning and Timing System.)

Question #3: "The soundhouse sent a signal every minute. How often does a satellite send a signal? What is the signal like?"

Actually, each satellite sends a signal continuously, rather like a radio station broadcasts 24 hours per day. The radio station signal can be considered to consist of two parts: a carrier, which is on all the time, and "modulation" of that carrier, which is the voice or music that you hear when you listen to the station. (You probably have detected the presence of the carrier when the people at the station neglect to say or play anything.[3] The carrier produces silence, whereas if your radio is tuned to a frequency on which no nearby station is broadcasting you will hear static.)

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[1] GPS time is almost identical to UTC time. At one time they were identical, but the world's timekeepers, starting in 1972, have had to insert a leap second occasionally to keep solar noon and the rest of the hours where they ought to be. The Earth's rotational velocity is slowing because of tidal breaking (oceans sloshing around). Leap seconds are added every year or two. But the basis for GPS time does not change. At the turn of the century UTC time was exactly 13 seconds ahead of GPS time.

[2] Once noted as nature's way of keeping everything from happening at once.

Each satellite actually broadcasts on two frequencies. Only one of these is for civilian use. (The military GPS units receive both.) The civilian carrier frequency is 1575.42 megaHertz (1,575.42 million cycles per second). In contrast, FM radio signals are on the order of about 100 megaHertz. So the GPS radio waves cycle about 15 times as often, and are, therefore, one-fifteenth as long: about 20 centimeters from wavetop to wavetop. As this goes to press there is serious discussion about adding one or two new civilian signals. Having two signals at different frequencies available allows a receiver to compute a more accurate position than does a single signal.

The modulation of the GPS wave is pretty dull, even when compared to "golden oldies" radio stations. The satellites broadcast only "bits" of information: zeros and ones. For most civilian use, this transmission, and the ability to make meaning out of it, is called the "C/A code"—standing for Coarse/Acquisition code. The word "Coarse" is in contrast to another code used by the satellites: the "P" or "Precise" code. The term "Acquisition" refers the capability that allows both civilian and military receivers to acquire the approximate position of the receiver antenna. The C/A code is a sequence of 1,023 bits which is repeated every one-thousandth of a second.

A copy of the C/A code for a given satellite might look like this:

1 0 0 0 1 1 0 1 0 0 1 0 1 1 1 1 0 1 1 0 0 0 1...

and on and on for a total of 1,023 bits. Then the sequence starts again. The sequence above probably looks random to you—as though you began flipping a coin, recording a "1" each time it came up heads and a "0" for tails. It is, in fact, called a **pseudorandom noise** code—the term "noise" coming from the idea that an aural version of it would greatly resemble static one might hear on a radio. The acronym is **PRN**.

Question #4: "How does the receiver use the 0s and 1s to determine the range from the satellite to the receiver?"

The PRN code is anything but random. A given satellite uses a computer program to generate its particular code. The GPS receiver essentially uses a copy of the same computer program to generate the identical code. Further, the satellite and the receiver begin the generation of the code at exactly the same moment in time.

---

[3] Dead air.

```
4:00 p.m. >>|               |<<<<<< 7/100 of a second
            |               |          after 4:00 p.m.
            |               |
            ↓               ↓

Receiver:    G J K E T Y U O W V W T D H K . . .
Satellite:                   G J K E T Y U O W V W T D H K
```
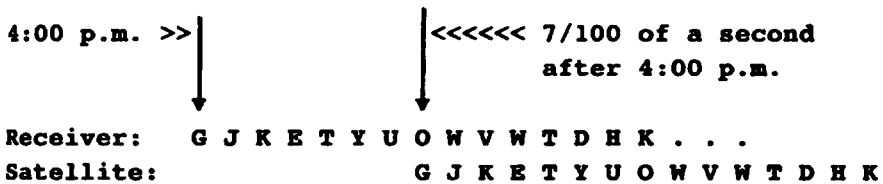
The receiver can therefore determine its range from the satellite by comparing the two PRN sequences (the one it receives and the one it generates). The receiver first determines how much the satellite signal is delayed in time, and then, since it knows the speed of radio waves, it can calculate how far apart the two antennas are in space.

As an example (using letters rather than bits so we can have a more obvious sequence, and cooking the numbers to avoid explaining some unimportant complications), suppose the satellite and the receiver each began, at 4:00 P.M., to generate one hundred letters per second:

G J K E T Y U O W V W T D H K...

The receiver would then look at its own copy of this sequence and the one it received from the satellite. Obviously its own copy would start at 4:00, but the copy from the satellite would come along after that, because of the time it took the signal to cover the distance between the antennas. Below is a graphic illustration of what the two signals might look like to the computer in the receiver:

The receiver would attempt to match the signals. You can see that the signal from the receiver began to arrive seven letters later than 4:00; the receiver's microcomputer could therefore determine that it took 7/100 of a second for the signal from the satellite to reach the receiver antenna. Since the radio wave travels at about 300,000 kilometers per second, the time difference would imply that the satellite was 21,000 (that is, 7/100*300,000) kilometers from the antenna.

Question #5: "The receiver must find ranges from at least four satellites to determine its position. How does the receiver "listen to" several satellites at once? Since all satellites broadcast on the same frequency, how does the receiver identify the satellites?"

The first thing to know is that each satellite has its own distinctive PRN code. In fact, the satellite numbers you were logging in the first assignment were the PRN numbers—which is the principal way satellites are identified. A satellite may also

have a number painted on its side, but it is the PRN number that counts. When an older satellite is retired, its replacement can take on its PRN number.

Most receivers have several electronic components, called "channels," that are tuned to receive the civilian GPS frequency. Although all channels are tuned to the same frequency, a single channel can track a GPS satellite by locking onto its PRN code. In more expensive receivers with several or many channels, each channel is assigned full time to tracking a single satellite. Other receivers "time-share" a channel—flipping it between satellites, as you might flip between channels on a TV, trying to keep track of two programs at once.

Question #6: "I've heard that the accuracy of GPS receivers was greatly increased recently when selective availability was turned off. What was selective availability? Why did it exist?"

Selective Availability, or **SA,** was the error deliberately introduced by the GPS managers in the C/A code broadcast to diminish the accuracy of GPS receivers. Sometimes the satellites lied about their positions. Sometimes they lied about when they sent the code.

What was the extent of the error caused by SA? The government guaranteed that 95% of the time a fix would be within 100 meters of the true position. To understand why SA existed you have to realize that the NAVSTAR system started as a military project to provide navigation for units of the armed forces. In the broad sense, GPS was designed as a weapons support system. One doesn't want one's weapons to fall into enemy hands. So steps were taken to deny use of the system to all but authorized receivers. In fact, the very existence of the GPS system, whose first satellite was launched in 1978, remained secret for several years.

It was never planned that you could buy a $200 receiver for your fishing boat. The military feared such uses as a terrorist with a mortar knowing exactly where he was, and hence being able to more accurately target his fire. Or the computer in a missile being able to monitor its position and correct its path during its flight.

If sufficient warning were given, of course, the entire civilian side of NAVSTAR could be shut down to deny its use to hostile forces. (The consequences would be disastrous, but not as much so as a nuclear war.) But, in any event, the military was still uncomfortable with allowing the best GPS accuracy in the hands of everybody. So why was SA turned off? As it turns out, very good accuracy may be obtained by using two GPS receivers in concert

(we explain this in detail in Chapter 4) and for the very best accuracy you need two receivers, SA or no. So SA became more of a nuisance that offered no real protection. In fact, the Army Corps of Engineers began broadcasting corrections to positions obtained by civilian receivers. Under pressure from the civilian GPS users, and other countries—Japan and European—who began contemplating their own version of GPS, using the more general term Global Navigation Satellite System (GNSS)[4]—the U.S. government abruptly clicked the SA switch off. This occurred on 2 May 2000, just after midnight Eastern Time. It was an important enough decision that the President made the announcement himself. The slim protection SA provided might be replaced and enhanced by jamming the GPS signals in selected geographical areas, if necessary. If you are interested in SA, and other matters related to GPS policy, you can go to the web site of the Interagency GPS Executive Board (www.igeb.gov) and find out considerably more than there is space for here. You can also view the President's declaration of 1 May 2000.

Question #7: "How is it that a satellite, cutting Earth's meridians at 55° and moving at 8600 mph, generates a track that is almost due north-south in the vicinity of the equator, as seen in Figure 1–1?"

While the satellite is moving very fast, it is also far out in space. Therefore the motion of the corresponding point on the Earth's surface along the satellite's track (picture where a line from the center of the earth to the satellite would intersect the surface of the Earth) is considerably slower—about 2100 mph. The satellite's track along the surface of the Earth moves at this speed toward the northeast on the upswing and southeast on the downswing, so the eastward part of its motion is in the same direction as the rotation of the Earth. Any given point on Earth's surface at the equator moves about 1050 miles per hour eastward due to Earth's rotation about its axis. The north or south component of the satellite's velocity is about 1700 mph, while the east component is only about 1200 mph. So an observer at the equator would see only a slow drifting (about 150 miles per hour) of the satellite to the east over the period of an hour or two.

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[4] At this writing, the Europeans are currently developing a particular GNSS called Galileo.

Question #8: "If the orbital period is 12 hours, why does each satellite rise and set about four minutes earlier each day? Could the NAVSTAR system designers arrange to have the same satellites in view at the same time each day in a given location?"

The short answer to the first question, if you know a bit of astronomy, is that the satellites orbit the earth twice during a **sidereal** (pronounced si-dear-e-ul, meaning "star based") day, rather than a **solar** (sun-based) day. A longer explanation: Suppose you look up at the stars on midnight of the first of April and note their positions. To see the same picture on May first you have to look up at 10:00 P.M. In the 30 days the stars "moved" 120 minutes—four minutes a day. Of course the stars didn't move; the earth rotated. By midnight it would have turned not only the 10, 800 degrees (that is, 360 per day times 30 days) from its daily rotation, but 30 degrees further (360 degrees multiplied by one-twelfth) from its yearly rotation in its orbit around the sun. The 10, 800 degrees works out to zero basically (you are back where you started from) but the 30 degrees is significant.

Or think of it this way: While each individual satellite is in orbit about the Earth, making its circuit exactly twice a day, the set of satellites are independently in orbit about the sun. They orbit the sun as a package—the rings of their orbit making up sort of a spherical birdcage. The cage is centered on the Earth and contains it. The Earth is a body that rotates independently within this cage. The cage does not rotate at all on its own axis, but orbits the sun.

To understand what "not rotating on its axis" means, realize that the moon rotates on its own axis once during each trip around the earth, so that it always shows the same face to Earth. If the moon did not rotate, we would see different sides of it as it made its way around the Earth. In contrast to the moon-earth situation, consider the cage-sun situation: the cage *does not* rotate on its axis and therefore does present different sides of itself to the sun over the course of a year.

So at any given time (say noon, when the sun is directly over a given meridian), a person on Earth will see (that is, "look through," toward the sun) one side of the cage on the solstice in January. But from the same point on earth that person would be looking through the opposite side of the cage in July. In effect, then, the cage will be seen from Earth to have made half a complete rotation around the Earth once each half year. To a person on the Earth, then, the cage apparently moves about 1/365th of a rotation per day. That amounts to about four minutes a

day—calculated as 1440 minutes in a day divided by the number of days in a year.

In answer to the second part of Question #8, if the satellite's orbits were boosted another 50 kilometers or so further out they would appear in the sky at the same place at the same time each day. The further a satellite is from the earth the longer its period—both because it moves more slowly and because it has further to go.

Question #9: "In earlier text it was suggested that it was somewhat more important that there be a good view of the sky to the south for good reception. Why?"

The statement about reception being better toward the south applies only to the middle and upper latitudes in the northern hemisphere. As you know, the satellites are in oblique orbits. Their tracks give the north and south poles a wide berth. In Figure 3–1 you are looking directly down on the north pole at satellite tracks generated over a six hour period. The dashed circle is a parallel at 45°, so you can see that there is a dearth of satellites overhead if you go very far north of that. There is still good GPS coverage—all the way to the North Pole.
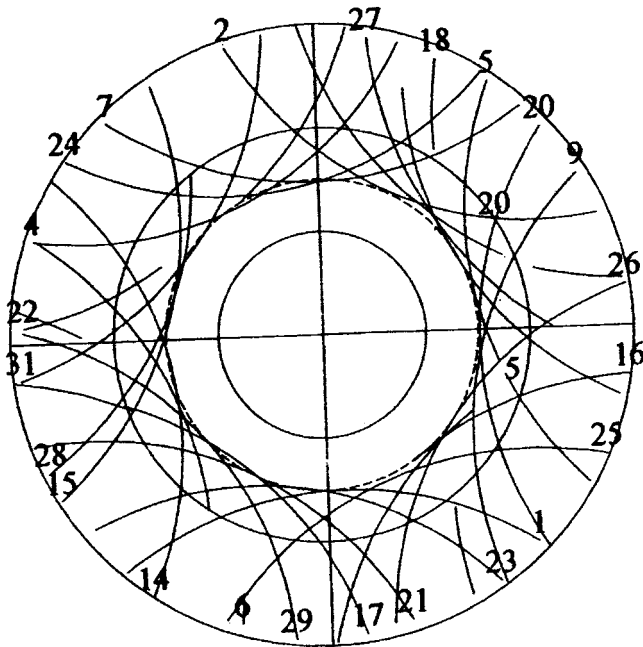
Figure 3–1. GPS satellite tracks seen from space looking toward the North Pole.

STEP-BY-STEP

Recall the story of the two "logically challenged" people who rented aboat and went fishing. They were highly successful—catching a lot of fish.Said "A" to "B," "Be sure to mark this spot so we can come back to it." Asthe day ended and they were approaching the dock, "A" asked "B": "Didyou mark that fishing spot?", to which "B" replied: "Sure I did, just like youasked me—right here on the side of the boat" There was a pause as theabsurdity of this penetrated "A's" brain. "You idiot! What if next time wedon't get the same boat?"

But now, as we move into a new century, you have a way of marking where you were. In fact, you have done so. In Chapter 2 you used the computer program GPS Pathfinder Office to upload files from the GPS datalogger into a PC. By use of the program you can determine where you are to within 5 to 15 meters. Our goal now is to look at those uploaded files, and some others, both graphically and statistically. You will also acquire an understanding of the quality of your data.

PROJECT 3A—Volcano

We begin by looking at a file generated by a GPS receiver that circum-navigated Kilauea Caldera, the active volcano on the island of Hawaii. Before you can see or analyze the data, however, several parameters must be set up. (Right. Just as when you used the GPS receiver. It turns out that, when you do GPS for GIS, a considerable part of the activity is getting settings right. Sorry.)

{__} Start the Pathfinder Office software as you did in Chapter 2. Close all open windows (except the main one, of course). Maximize the window.

{__} In the File menu, pick Projects. Click on the field next to "Project Name." Find "Default" in the drop down list (you may have to scroll the list up or down to see all the entries) and click on it. Okay your choice.

{__} Under the "Options" menu, select "Coordinate System." You want to "Select By" "Coordinate System and Zone" (rather than "Site"). The "System" should be "Latitude/Longitude" and the "Datum" "WGS1984." Altitude should be measured from mean sea level in meters (use the EGM96 [Global] Geoid). "OK" your choices.

{__} Under "Options ~ Units" pick kilometers for the Distance measurement.

{__} Under "Options ~ Time Zone" pick "Hawaii." Notice that Hawaiian time is 10 hours earlier than Greenwich (UTC) time.

{__} Also under "Options," turn off all five "bars" (four "Toolbars" and the "Status Bar") by clicking each so that the check beside the toolbar name disappears. Now turn on the Standard toolbar. Run the mouse pointer over it, pausing over each button long enough to read the explanatory box that appears. Do the same now for the Mouse toolbar. Add and checkout the Project toolbar. Likewise the Utility toolbar. Finally, make the Status Bar appear at the bottom of the window. (Part of the trick to operating complex software is reading and understanding various messages that it provides—that is, keeping up with the status of the program. Another part is knowing the major capabilities—illustrated here by various buttons on the toolbars.) The completed window will look like Figure 2–10 in the last chapter.

{__} Under Options, instruct the software *not* to save the window layout when the program is exited.

{__} From the File menu, click on "Open." A window entitled "Open" will appear. (To achieve the same effect, you could also have clicked on the little yellow file folder icon at the left of the standard toolbar.)

{__} Fill in the blanks in the window so that the directory is __: \GPS2GIS\HAWAII[5] and the file is "Volcano.ssf." (The following step contains detailed instructions.)

{__} ***Navigate to the correct file:***
(1) click on the little down arrow in the "Look in:" box and, from the drop down list with a mouse click, pick the choice that says something like "My Computer" or "This Computer." (Use the slider bar or arrows at the right of the window to see all the choices if necessary.);

(2) within the large white area of the "Open" window select the icon associated with the disk drive "__:" with a single mouse click (it will become highlighted) and tap the "Enter" key (or double-click on the icon, which comes to the same thing);

(3) **pounce**[6] on "Gps2gis" from the list that appears (you may have to use the slider bar at the right to get to it); alternatively use the down and up arrow keys to move the highlight);

(4) pounce on "Hawaii"; (if you pounce on the wrong item you can backtrack by clicking the file folder with the "up arrow" next to the "Look in:" box);
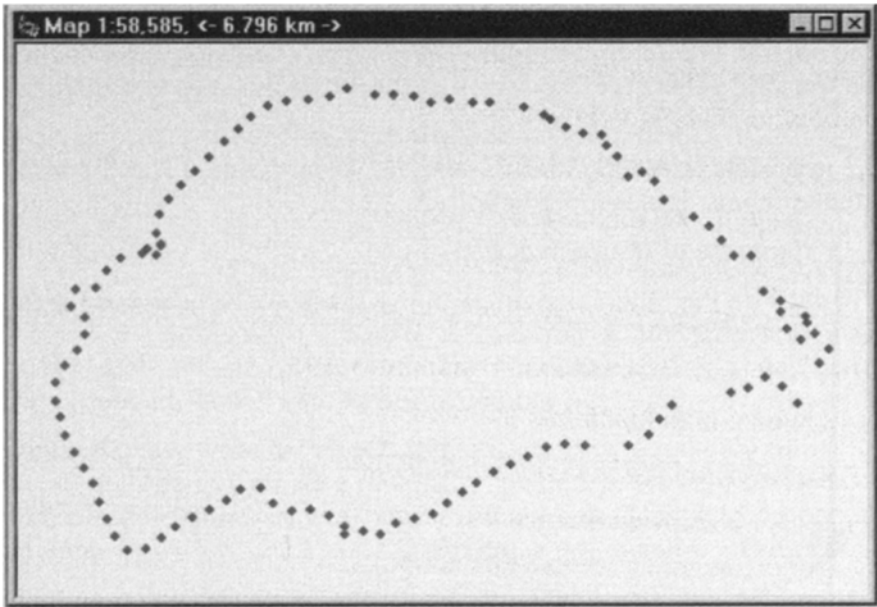
Figure 3–2. GPS track around Kilauea Caldera volcano.

(5) the "Files of Type" box should say "Data files (ssf, cor, phs, imp)." (If it doesn't, select this option from the drop down list.);

(6) under "File Name:" select (with a single click) "Volcano.ssf" but *don't open the file yet*. Note, from the information at the bottom of the "Open" window, that the data collection start time was approximately 2:50 P.M., local time, on 15 February 1994. The file is made up of 110 points and occupies 12.9 kilobytes (KB) of storage. (If it doesn't say this, you did something wrong above. For example, if you picked the incorrect time zone, the date and/or time might show up incorrectly.) Now click the "Details" button (it's to the far right of the "Look in:" box) to see information about this and the other files in this directory. You can see file name,

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[5] Place in the blank whatever hard drive disk identifier your instructor tells you is correct.

[6] From now on, we'll call a single click on a choice, followed by pressing the "Enter" key, a **"pounce."** You can also "pounce" with a double click but there are reasons not to do this if you aren't too familiar with Windows and/or the application software. For one, double-click speeds are user selectable and a previous user may have selected a speed that makes your double-click not work and leaves you wondering what happened.

size, type, date the file was last modified, and attributes—either by moving the horizontal slider bar or resizing the column widths by dragging their separator bars.

{__} Click "Open."

{__} Display the map by clicking "Map" in the "View" menu. It may look something like Figure 3–2. Or it may not. Or it may be that nothing appears in the window at all. No matter! You have a lot of control over the appearance of the map, as you will see in the next few steps.

{__} From choices that show up under "View," select "Layers" then "Features." The window that shows up (Feature Layers) contains a list of feature-type names.

The data you are working with consists of simple position data (fixes consisting of a latitude, a longitude, an altitude). In Pathfinder Office such raw data are called "Not In Feature" data. (Positions may also be collected in such a way as to be associated with particular features, such as roads or types of vegetation, and these features may have names; I'll discuss the collection of such "feature attribute data" later in detail.)
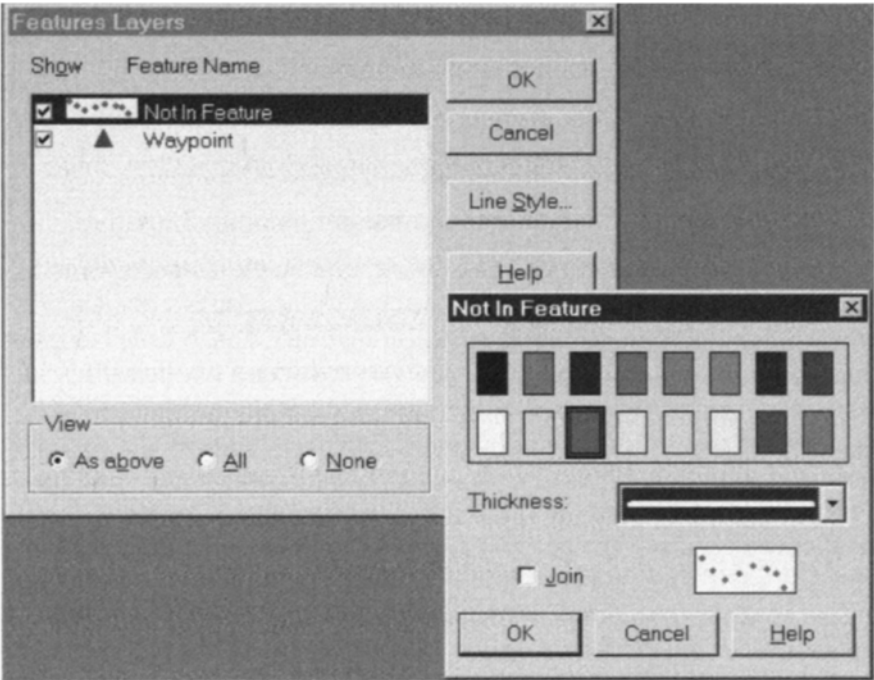
Figure 3–3. Defining feature-type symbology.

{__} To change the way raw-position data appear on the screen map, single click on "Not In Feature" so it is highlighted. A box next to the name shows the symbology with which data are displayed. A checkmark, toggled with a mouse click in the box in the "Show" column, determines whether the layer will be visible or not. Make certain that "Not In Feature" has a checkmark beside it. The data you are working with consists of individual points that are not part of any other feature—hence the "Not In Feature" designation. (Make sure the "View" option in this window is set to "As above.")

{__} In this same window, press "Line Style." A "Not In Feature" window appears. Here you can select a symbol color, a line thickness, and whether or not you want adjacent data points connected with line segments. Pick a medium line of red color with the data points not joined. (Please see Figure 3–3.) Okay your choice.

{__} Verify that your choices of "Line Style" made it to the "Features Layers" window. Click OK there. Now the map should look like Figure 3–2 (except for the color). (Don't "Maximize" this window; if you do the map scale and distance information bar at the top of the window will disappear!)

Explore the Map

{__} What map scale appears on the map?_____.

A map scale can therefore be considered a single number, namely a fraction; it is usually much less than one (1.000); its form is 1 divided by x, where "x" is usually a number much larger than one. A map scale is a ratio: the distance on a given map to the equivalent distance on the earth's surface—each number expressed in the same units. If the number "x" is one (1.0000) the map is said to have full scale. Other ways of putting it would be that the map scale is 1.0/1.0, or 1:1, or 1 to 1—all of which imply full scale. Farmers would object if you began unrolling such maps. As the scale gets smaller (nearer zero) less detail is displayed and more real estate is shown on a given size page. Many people incorrectly reverse the meaning of large and small scale; they look at the denominator of the fraction, rather than the fraction itself. A 1:250 scale map is a larger scale map than a 1:500 scale map. One divided by 250 is 0.004; one over 500 is 0.002. The number 0.004 is larger than the number 0.002. Remember it this way: Larger scale maps have a larger degree of detail.

{__} Does the number of kilometers indicated at the top of the map refer to the distance from one side of the track to the other, or to the width of the window? _____ (Hint: resize the east-west dimension of the window.)

{__} Experiment with different types of "Distance" units from the "Units" window, created by selecting from "Options ~ Units." Note the change in the value of the east-west dimension of the window (shown in the map border at the top) reflecting that different units have been specified. Try inches.[7] Finish up by selecting "Meters" as the distance units for the data set display.

{__} Since you have resized the window, you may want the image to fill it. Select View ~ Zoom ~ Extents and note the results. Now resize the window again so that part of the figure is cut off. This time find the magnifying glass icon with the equal sign (=) in it; press it. Again you get a "Zoom to Extents."[8]

{__} In the "Units" window, set the "Area" to be "Hectares." (A hectare is 1/100 of a square kilometer. A hectare contains the same area as a square that is 100 meters on a side—but of course it might have any shape; there are about two and a half acres in one hectare.) Set the "North Reference" to be "Magnetic" (Automatic Declination), so Pathfinder Office will automatically calculate the **declination** (i.e., the difference in degrees between true north and magnetic north).[9]

The map will show features oriented toward true north regardless of whether "True" or "Magnetic" North is selected. However when the Measure capability of Pathfinder Office is used, the direction of measuring lines will be shown in True or Magnetic degrees, depending on which is selected.

{__} Under "Options ~ Style of Display" choose the "Lat/Long Format" DD*MM'SS.ss" which will cause the software to display latitude and longitude coordinates in the form of degrees followed by minutes, followed by seconds including decimal fractions of seconds.[10] The other forms of display are DD*MM.mmm' and DD.ddd. Could you express 49°30'30.66" (forty-nine degrees, thirty minutes, and thirty point six six seconds) in these other two forms?

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[7] The map scale shown is only approximate. Depending on the size of your monitor it may be off quite a bit. You can check by making the window 10 inches wide (use a ruler), multiplying the value in the denominator of the scale shown by 10, and seeing if this agrees with the distance, in inches, given at the top of the window.

There are 60 minutes in a degree; there are 60 seconds in a minute.[11]

(1)_____ (2)_____

{__} Now under "Options ~ Style of Display" change the "Lat/Long Format" to DD*MM.mmm'. Push the "Select" button (its icon is an arrow, pointing about north-north-west). Move the pointer around the map and observe the change in the "minutes" value shown on the Status bar. Recall that a minute of latitude is about 1845 meters. In general, the Status bar will display the coordinates of the map position indicated by the pointer.

{__} Change the style of display to "DD.ddd."

{__} *Determine some data point coordinates:* Slide the pointer down over the map. Note the status bar (at the bottom of the screen): the numbers there tell the latitude and longitude of the end of the pointer in decimal degrees. Position the pointer near the center of the "oval" made by the GPS track. Write down a latitude and longitude: _____. If you click near a point on the GPS track, an "X" will appear, jumping to the nearest data fix. Try this. If you move the pointer off the map window the status bar will tell you the coordinate system in use. Try this.

A number of Internet sites allow you to display maps at various scales. At the time of this writing (and bear in mind that worldwide web sites are constantly in flux) there are sites that allow you to put in latitude-longitude coordinates and obtain a map of the surrounding territory. Some such sites are www.mapquest.com, www.esri.com, www.mapblast.com, and www.mapsonus.com.

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[8] As with many operations, there are multiple ways to achieve the same state. I won't point them all out. Once you become comfortable with the operations of Pathfinder Office you can look at the buttons and determine what shortcuts might be useful. Some the menu options have buttons; some don't.

[9] The Lat-Lon graticule is based on the location of the axis about which the earth spins—and that axis defines the **true** north and south poles. The **magnetic** north pole is the place toward which compasses point. It is in very northern Canada at approximately 75° north latitude and 100° west longitude.

[10] The degree symbol is not particularly easy to produce on a computer, so Pathfinder Office lets you substitute an asterisk (*).

[11] To convert degrees, minutes, and seconds to decimal degrees, divide the seconds by 60, add the result to the minutes. Divide that sum by 60, then add this last quotient to the number of degrees.

{__} If you have access to the Internet, minimize Pathfinder Office and go to a site such as www.mapquest.com and find where you can get a map based on its latitude and longitude. Type in the latitude and longitude values you wrote down above (remembering that **west** longitudes are **negative** numbers). If the map-serving people have done their job correctly you should see a map of the road around the volcano. The central location indicated on the map should be approximately the location you indicated on the Pathfinder Office portrayal of the GPS track. Note the similarity with the GPS track.

{__} Back in Pathfinder Office with the Map window active, using the mouse, run the pointer along the icons on the mouse bar. Usually an explanatory box appears if you pause briefly over an icon. Find the one that allows you to measure distances on the map. (It looks like a ruler; you can also find its equivalent "Measure" in the "Data" menu.)

{__} ***Measure some distances:*** Click "Measure." If you now click any location on the map near a vertical edge and then drag the cursor around, you can see that the Status Bar displays the distance and direction of the line in the units you have set for the display. Measurement takes place to the little "+" sign cursor. Swing the measuring line around so that it is vertical, toward the north. Note that magnetic north is about $10°$ to the east of true north. That is, to go directly north you would have to follow a compass course of $350°$.

{__} If you now click the left mouse button again you will anchor the moving end of the line and will see a display of the length and direction of the line. You can continue the measuring process, although you no longer get immediate displays of the values. Each time you click the mouse button you get another anchor and indication of the total distance measured from the first anchor to the last. The direction of the last line anchored is shown as "Bearing." You also get a reading for "Area."

Under the right conditions, if an imaginary line were drawn from the last anchor to the first anchor (the starting point), the sequence of lines might define a polygon; the area indicated is the area of that polygon. If the polygon is not properly defined (that is, if any of these lines [including the imaginary last line] crosses any other), then the area number displayed is meaningless.)

{__} To end the measuring process, and start another set of measurements, make a final anchor with a double click.

{__} Measure the distance from the leftmost side of the map window to the rightmost. It should agree approximately with the legend at the top of the map. Measure some other distances. What is the distance between the two points furthest apart on the GPS track?_____

{__} Change the Distance units to Miles and the Area units to Square Miles. Change the Not In Feature type so that the GPS points are joined. (Use View ~ Layer ~ Feature.) Measure and record here the approximate length of the overall GPS track. _____. What is the area of the volcano inside the track? _____. Under Options ~ Units choose True North. Switch measuring off, by clicking the Select icon next to the "Measure" tool.

Examine Properties of GPS Fixes

{__} ***Determine the location, time of acquisition, and other properties of a particular point:*** Choose "Position Properties" either from the "Tool" icons (it's a "+" sign with a "?" mark) or from the "Data" menu. A "Position Properties" window will appear. Resize the map window and move the Position Properties window so that they do not overlap. (You may have to "Zoom to Extents" so you can see the entire GPS track.)

{__} Select a position anywhere on the map (but off the GPS track), clicking with the left mouse button. Note the results in the Position Properties window. Now select a position on the GPS track with the mouse. Note that the Position Properties window gives more information: You should see latitude, longitude, meters above mean sea level, the date and time the point was taken (in local time, to the nearest one-thousandth of a second), the position sequence number, and the "status" (whether it is a 2-D or 3-D point and whether the fix has been "corrected"). (In any of the work in this book, if you see a 2-D point, it generally means an error has been made in collecting the data.)

{__} By choosing the DOPs tab in the Position Properties window you can see the PRN numbers of the satellites that were used to determine the position. If the receiver had been set to record DOPs at the time the reading was taken, those values would appear as well.

{__} The buttons at the top of the Position Properties window ("First," "<<," and so on) will allow you to look at the first point (First), the next point (">", not ">>"), the last point (Last), and so on. Use these tools to move the point selection (a little "x") along

the path of the GPS track. In which direction was the road traversed? Clockwise ( ). Counterclockwise ( ).

{__} About what time did the trip begin? _____ What are the coordinates? _____ Record the same information for the end of the trip. _____._____.

{__} Approximating from the distance measurements you took from the display, estimate the average speed, in kilometers per hour, of the car that was carrying the antenna. _____ .

Looking at More Detail

{__} From Data ~ Position Properties, select the location of the beginning point of the trip (use First). Close the Position Properties window.

{__} Use the "Zoom In" tool (a magnifying glass with a "+" on it) to point to the approximate area of the beginning of the trip and press the left mouse button. The area identified will move to the center of the screen and the distance between the points will be magnified. Notice that the scale and the distance across the window change. The distance across the window is halved; the scale is doubled. Zoom in again. Again.

{__} Notice also that the track becomes more jagged as you zoom in. You can tell that it consists of a series of points connected by straight-line segments. Use the measure tool to get an idea of the size of these "jags." While the road might have followed this jagged course (it didn't—I was there) it seems more likely that the deviations are due to error in successive readings. I discuss these errors in considerable detail in Chapter 4.

{__} Now demagnify the area using the "Zoom Out" tool (select it from the "View" menu). Which icon is equivalent to this menu choice? _____ You can Zoom Out by simply clicking in the Map window. Zoom out again. Again.

{__} From the "View" menu, choose "Zoom ~ Extents" to return to the original GPS track display.

{__} Repeat the above "zooming" steps, but instead of simply clicking a point, drag a box around the area of interest. When zooming in, map features inside the box you drag are enlarged to fit into the map window. When zooming out, the box you drag suggests the box that you want the entire currently-visible portion of the map to fit into. The smaller you make this box, the greater the degree of "zooming out." The map features shown before the

zoom out will fill this box; those features will be centered at the center of the box. Finish this step by Zooming to Extents.

The file B021602C represents the first part of the drive back from the volcano. The trip back also includes the files B021603A and B021604A.

{__} ***From the same window from which you opened VOLCANO.SSF, open B021602C.SSF while also retaining the existing (VOLCANO) file:*** There is a trick here. You may open several files at the same time by selecting the first one with a simple left mouse click on the icon. Add successive files by holding down the "Ctrl" key and clicking on the file name icons that you want to add. (You can also "deselect" file names by holding down the control key and clicking on a file name icon.) Once you have the set of files you want opened (two files, in this case) press Open and the window will disappear, leaving you with a recomputed map.

{__} Get the "Open" window again by clicking on an icon. Now add files B021603A.SSF and B021604A.SSF. Another trick: if you hold down the Ctrl key before you begin selecting files, those files currently open, indicated by shading, will also be selected as you select new files.

{__} Now open just the VOLCANO.SSF file by itself and display it.

Manipulating Files

{__} ***Select the three files leading away from the volcano to prepare for combining them into a single file:*** Under the menu "Utilities" select "Combine." In the resulting "Combine Data Files" window, press "Browse" to bring up a list of files in the folder. Note that as you highlight a file name by (single) clicking on it, you get information on that file. Pick the three files from the list, using the same approach as you did when you opened them originally. (The little input line under "File Name" may not be large enough to contain all the names, but if they are highlighted in the list they are set to be combined.) Click "Open" to send the file names to the "Combine Data Files" window.

{__} ***Combine the three files into a single file named "AWAY.SSF":*** Press "Output File." Navigate to __:\GPS2GIS \HAWAII, so that the "Save in" directory field says "Hawaii." Under "File Name" type "AWAY.SSF." Press the Save button. (You may have noticed by this time that file names are not case-sensitive. I use caps here in the text for better contrast with the other words
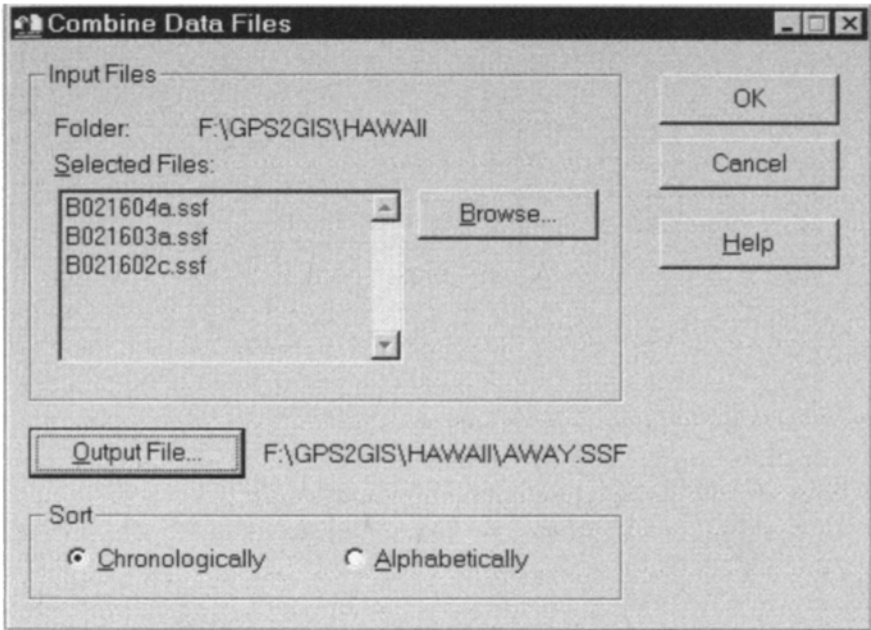
Figure 3–4. Combining multiple data files.

in the sentence.) Back in the Combine Data Files window, make certain that the "Sort" section indicates that the files should be combined chronologically (in time order) and, after checking all the parameters, okay the "Combine Data Files" window. Review the information (it should appear as in Figure 3–4) and then click OK. If you are told the file AWAY.SSF already exists, elect to overwrite it.

{__} Return to "File ~ Open" and open the two files VOLCANO.SSF and AWAY.SSF. You should see the trip around the volcano and the return trip. Open the Position Properties window and select points along each route—noting the file names.

The trip **to** the volcano was along the same two-lane road as the trip away from it. The "to" trip was recorded as B021520B.SSF.[12]

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[12] Note the name of the file **to** the volcano. The name implies that the file data were collected on the previous day (15 February). Well, it **was** the previous day in Greenwich, England. In Hawaii this all took place in one afternoon. (Not only was the day different on the Big Island, the weather was better.) The point here is that the file names are based on UTC time, not local time.

{__} Open VOLCANO.SSF, AWAY.SSF, and B021520B.SSF. Note that it is hard to distinguish between AWAY.SSF and B021520B.SSF.

Pathfinder Office allows you to represent different features types with different symbols. But it doesn't allow you to represent different files of the same feature type with different symbols. Since all three of the displayed files are of feature type "Not In Feature," they are all displayed in the same way. I would like you to see the B021520B file and the AWAY file with different symbols so that you can contrast them. I propose a ruse. Usually, different feature types are generated with a data dictionary, of which more later. But the software allows three feature types to be made from Not In Feature data. They are Point_generic, Line_generic, and Area_generic. The ruse is that we are going to convert the B021520B file into a Line_generic file so we can display it differently. We will use the Grouping Utility, normally used to group a number of files together, to convert the B021520B file.

{__} *Use the "Grouping" utility to take the Not In Feature data ofB021520B.SSF and convert it into the "Line_Generic" feature type:* Under "Utilities" select "Grouping." (Or you could press the Grouping icon on the vertical Utility bar.) On the Grouping window in the Selected Files section, click "Browse," navigate to and select the B021520B file. Click Open. For an Output File, navigate to the __:\GPS2GIS\HAWAII directory. Reject the suggested name "grouped.xxx" and use TOWARDS.SSF instead. The grouping method should be "One group per input file" and the feature type you create should be "Lines." Read the "Tip" at the bottom of the page, then click OK and the utility will finish. (If it complains that the file already exists, select the option that lets you overwrite it.) Please see Figure 3–5.

{__} Open the SSF files VOLCANO, AWAY, and TOWARDS. Under View ~ Layers ~ Features change the "Not In Feature" line style to the thinnest green line. Change the "Line_generic" symbol to moderately thin unconnected black dots. Check the boxes so that all will be shown on the map. Once they are displayed, the dots from TOWARDS will overlay much of the line from AWAY. You can form an idea of the degree to which these tracks are congruent.

{__} Make sure the units are Meters. Pick a southern part of the road to the volcano and zoom up on it a lot (so that maybe only five or so dots of TOWARDS.SSF show). What is the approximate distance between the dots? _____
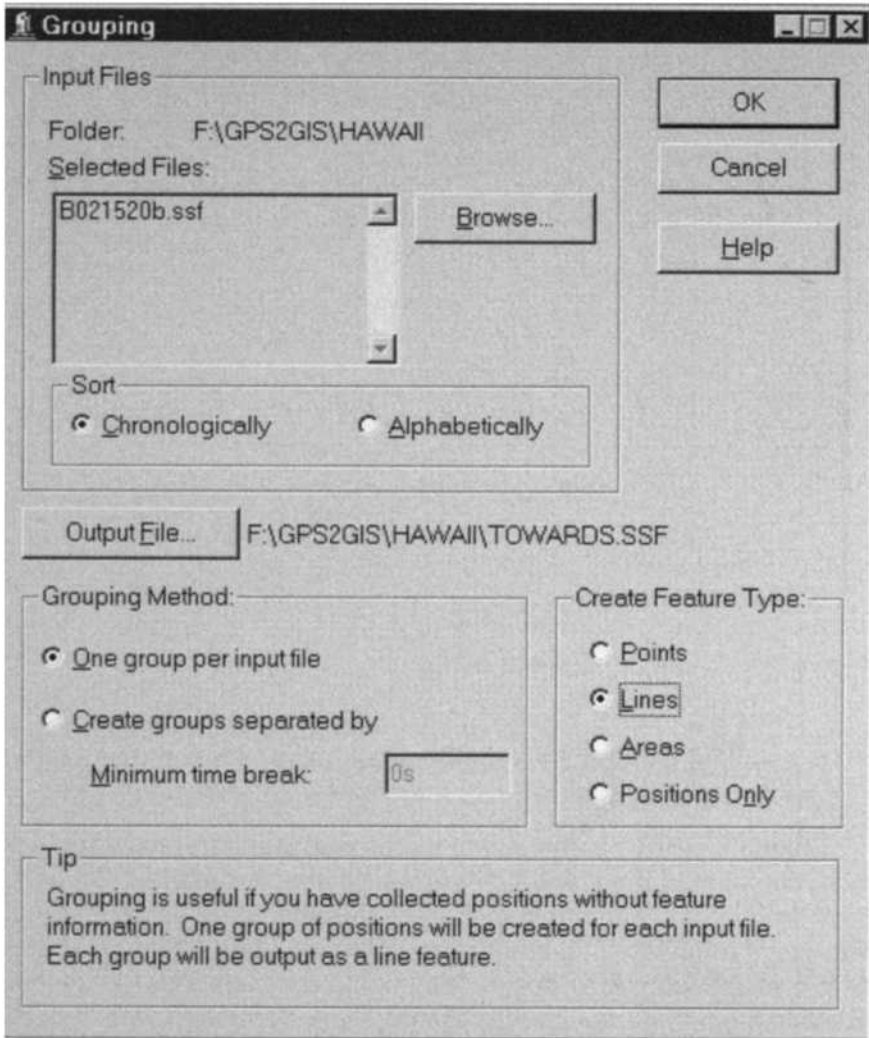
Figure 3–5. Using grouping to change feature-type.

{__} Zoom way up on a single dot (pick one that stands away from the line a bit) so that only it appears on the map with the green line. What is the distance between the TOWARDS.SSF dot and the AWAY.SSF line? _____. Since the width of this two-lane road is only about six meters, to what do you attribute the difference you measured? _____ Zoom Extents.

{__} You've seen the window that will allow you to keep Not In Feature data from being displayed. Find that window and turn off

the volcano track and the drive away from it. The "Big Island" has two major cities. Using a map or atlas or the Internet, determine from which city the GPS track TOWARD the volcano originated. _____.

{__} Finally, from the Data menu, turn off the Position Properties window. From the View menu turn off the Map.

PROJECT 3B—Rooftop I

In this exercise you will find a single point in 3-D space that approximates the location of an antenna that collected data at a fixed location. We look first at a file of points taken by a GPS receiver whose antenna was stationary over a period of time before selective availability (SA) was turned off. These GPS readings were taken from the top of a roof of a house in a Kentucky city. The idea here is that we are trying to locate a single geographic point as accurately as possible. To do that we take lots of fixes and average them. The data taken were "Not In Feature" data but we will convert them to a single Point-generic datum so we can plot the fixes. Then we take a look at three files taken at the same place after SA was turned off.

{__} Start the Pathfinder Office software if it is not already running.

{__} Make a new project named ROOF_yis, where "yis" represents your initials. Be sure the "Project" references the directory __:\GPS2GIS\ROOFTOP. (You will be told that the folder already exists and asked if you want to continue anyway. You do.)

{__} Prepare to open the file B022721 A.SSF which you will find in the directory __:\GPS2GIS\ROOFTOP. (The right directory, with the right file name, should come up since your active project is ROOF_yis and it references the ROOFTOP directory.) Write the day and month of the file, as indicated by the file name, (_____) and then open it—but don't map it yet.

{__} Change the coordinate system to Universal Transverse Mercator. Set the UTM zone to 16 North.[13] Change the datum to the North American Datum of 1927 (NAD 1927) (Conus means Continental US, Coterminous US, the lower 48 states). Make certain the units are meters. Set the time zone correctly based on the file date. (The city is in the Eastern time zone. Daylight savings time runs from the first Sunday in April to the last Sunday of October.)
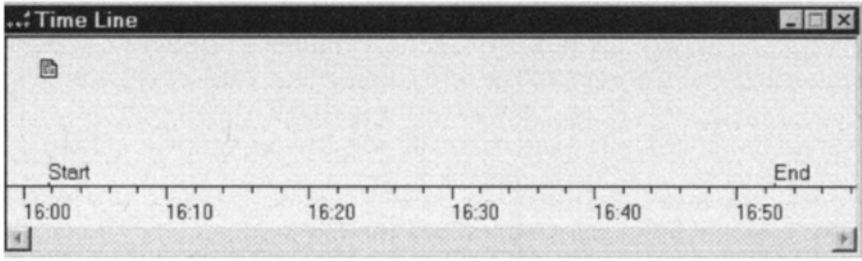
Figure 3–6. The time span of the rooftop file.

{__} Under "View" select "Time Line." Note the appearance of a window showing the start and end times of data collection. Stretch it out horizontally. Zoom to Extents. (See Figure 3–6.) Use the "F1" key to get context sensitive help. Read about the time line. It will be a lot more interesting later when we collect attribute data with the position data. Examine also the table of contents of the help window. When done, dismiss the help window.

{__} What was the weather like the afternoon the data were taken? _____[14]

{__} Select "Map" under "View." You will get a map box but may not get a map. Why not? _____. If you don't know, there's a hint in this footnote—though you can probably figure this out without it.[15]

{__} Under View ~ Layers ~ Features, make sure there is a check mark so Pathfinder Office will show Not In Feature data; use a thin red line with the points joined. Apply Zoom Extents to both the map (after making it active) and the Time Line (after making it active).

{__} Now that you can see all the fixes that have been taken, what is the approximate distance between the fixes farthest apart? _____

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[13] I could have asked you to calculate the UTM zone from the latitude and longitude. You will have to do that in the future. For the formulas to calculate the correct UTM zone for a latitude and longitude pair, see Exercise 3–4.

[14] Just checking to see if you were paying attention. Interestingly enough, we could have attached other devices to a GPS receiver that would have let us know a lot about the weather. More about that later.

[15] In the last project I had you turn off Not In Feature data in Feature Layers.

{__} For the most part, the time-adjacent points you see here are close together in terms of location. The GPS track meanders around the space sort of casually. But note that toward the middle of the window some jagged spikes appear. Zoom up on them. With the selection tool, select a point at the end of one of the spikes.

{__} Open the Position Properties window and select the DOPs tab. Use the mouse-driven selection tool and the > and < keys to move along the GPS plot. Note that a point at one end of a spike is computed by using one set of four satellites, while a point at the other end uses a different set.

By using Position Properties and moving from point to point with > and <, you were able to see that some time-adjacent points were recorded in widely different positions. What is going on here is that the four-satellite "best PDOP" constellation switches from one set of four satellites to another and then changes back again. This can happen if a satellite's signal is blocked by the operator's body or some other opaque entity—or if the process of calculating PDOP gives alternating results when the values are very nearly the same. Such spikes make the plot ugly and cause the receiver to use some additional memory for recording the satellites in the new constellation. But in Chapter 4 you will see that there is a way to eliminate much of the variation of the fixes from the true position value.

{__} In Position Properties click the Summary tab. How many points are there? _____. Over what period of time was the file col lected? (Click First and Last; also see the Time Line.) _____. What UTM Zone contains the points? (Check under Options, Coordinate System, presuming you set it correctly.) _____. What city contains the points? (You might have to change the coordinate system to latitude and longitude and then go to an atlas or a world wide web site _____.)

Make a single point that represents the fixes

We previously used the Grouping utility to convert raw (positions only) GPS fixes into a Line_generic feature—recall converting the GPS track toward the volcano in Project 3A. This time we will convert a set of raw GPS fixes into a single point, of feature type Point_generic. In general, Grouping allows you to use one or more input files to create output file(s) with features. We will use it to average a set of points in a file (that is, make a single point such that the x-coordinate is the arithmetic mean of all the x values,

same for y, same for altitude [z]). The feature type Point-generic allows us to pick a symbol for mapping the point.

{__} ***Make an SSF file that consists of a single point that represents the centroid (the three averages) of all the points in the file:*** Under Utilities select Grouping (or pick it off the Utilities Toolbar). For the input we will use only the 900-point file B022721A.SSF in the GPS2GIS\ROOFTOP directory. Put the output into the ROOF_yis Project directory __:\GPS2GIS \ROOFTOP. The software proposes that you call the output file "GROUPED" but you should make it instead "ROOFMEAN.SSF." Under Create Feature Type, select Points. Click OK. The Grouping utility will create a Point_generic file named ROOFMEAN.SSF consisting of a single point. The file B022721 A.SSF will remain as a 900 point Not In Feature file.

{__} ***Display ROOFMEAN.SSF in red, using a round symbol:*** Open both B022721 A.SSF and ROOFMEAN.SSF. Select Point_generic from the View ~ Layers ~ Features window, then select the Symbol you want. Also set things up so you will display B022721A.SSF with a thin, light cyan line. Draw the map with both files represented.

{__} Use the pointer to select the point that represents ROOFMEAN .SSF. (When it is selected a box will appear around it.) Since the ROOFMEAN.SSF file consists of a single point, what you have here is a graphical representation of the 3-D centroid— the three means (averages) of the 900 Cartesian points, though of course you cannot see the altitude dimension. Use Position Properties to assess the altitude. What is it? _____.

ROOFMEAN.SSF represents the best approximation you can make of the actual location of the antenna, if all you have to go on are the data in B022721A.SSF. In Chapter 4, which discusses differential correction, you will see how this approximation can be improved considerably.

When SA went away things got better—a lot better.

Now that SA has been turned off, individual fixes are almost always closer to the true position of the antenna. To demonstrate this, you will simultaneously open three files taken in the same place as the original, but without the intentional perturbation of SA. Then you will average the fixes in these files and look at how they compare with ROOFMEAN.SSF.

{__} Open the files A090214A, B, and C together and display them. Measure the distance between the fixes furthest apart. _____. Compare this with the distance you measured before for B022721A.SSF. A great improvement, no? So in terms of raw fixes collected by a GPS receiver, the variance has been improved by about an order of magnitude (a factor of 10).

{__} Use the Help menu to read about the Combine command (you used it before) that lets you concatenate[16] GPS files so that they form a single file. Then combine A090214A, B, and C together to form ROOF_NOSA.SSF.

{__} Use the Grouping utility to produce a single point from the fixes of ROOF_NOSA.SSF to produce ROOFMEAN_NOSA.SSF. Open ROOFMEAN.SSF and ROOFMEAN_NOSA.SSF and view them. How far apart are they horizontally? _____. Vertically _____.

A couple of things are interesting here: First is that the two points are so close together horizontally, despite the large spread of the fixes of the files. Though we don't know the actual true point we can infer that averaging works! Secondly, the altitudes are much worse than the horizontal distances. That is simply a characteristic of GPS—though usually the errors are not this great. Bear in mind that we have not yet applied the correction mechanism that we have waiting in the wings.

PROJECT 3C—New Circle Road

Here you will examine another file taken while moving the antenna along a path. You will look at using the "Pan" and "Auto-pan to Selection" features. Additionally you will get an idea of how differential correction can improve data accuracy dramatically.

Lexington, Kentucky is circumscribed by a (mostly) limited-access ring named New Circle Road. Unlike many cities, Lexington's street pattern resembles a bicycle wheel—spokes and rim—rather than a grid. A car proceeded from the south, entered the circle road heading west, and proceeded around the city, exiting at every major spoke, making a "U" turn, and reentering the circle. The primary results of this operation were a GPS file named

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[16] Concatenate: a 50-cent word that means "to connect end to end." You can make the word concatenate by concatenating the text strings "con," "cat," and "enate."

NEWCIRCLE.SSF and a police warning regarding illegal "U" turns.

{__} Set up Layers in View so that Not-In-Feature files are displayed with a thin gray line. Make the Distance units Miles. Open NEWCIRCLE.SSF which you will find in __:\GPS2GIS \CIRCLERD. The plot should look something like Figure 3–7.

{__} Zoom up so that the southernmost area of the GPS trace, including the entire north-south segment, fills the window.

{__} *Move the image on the screen using "Pan":* Select Pan from the View menu or the Mouse Bar icon. Place the crosshairs on a point on the image (somewhere other than the center of the window) and click. Note that the image shifts so that the point selected moves to the center of the window. If you lose the image completely, use the "Zoom to Extents" tool to recover the entire image. Then zoom up again.

{__} As with zoom, you can also use drag with Pan active. Select a point on the GPS track and drag it to any desired new position. If you lose the image completely, use the "Zoom to Extents" tool to recover the entire image. Then zoom up again.

{__} Use the "Pan" tool to slide the image northward from the southernmost point, then westward around New Circle Road to the next exit. You can see the track going up the right side of the arterial going north-north-east, and again in the right side coming back after the "U" turn. You can also imagine the exit and entrance ramps leading from and returning to the track of the limited access road. Continue to pan around the image until you feel proficient with the panning tool. Now Zoom to Extents and, with Position Properties, select the first point.

{__} *Explore "Auto Pan to Selection":* In the View menu, with the Map window active, put a check beside Auto Pan to Selection, or click the Auto Pan icon to turn this feature on. Use Position Properties to select Last to place a marker on the last point of the GPS track. Now click on First (they are in about the same location; it was a complete circuit). Zoom In tightly on the selected point again. Now begin changing the selected point with the Next button (">"). Notice that when the selection would address a point that is outside the window, the selected point is moved back to the center of the window. Pan partway around the circle in this manner, perhaps with different levels of zoom. Note that you can't lose the image. Note also that it is pretty jagged in spots.

{__} *Add a new file to the display—one that mimics the previousone, but whose positions have been corrected:*[17] Open
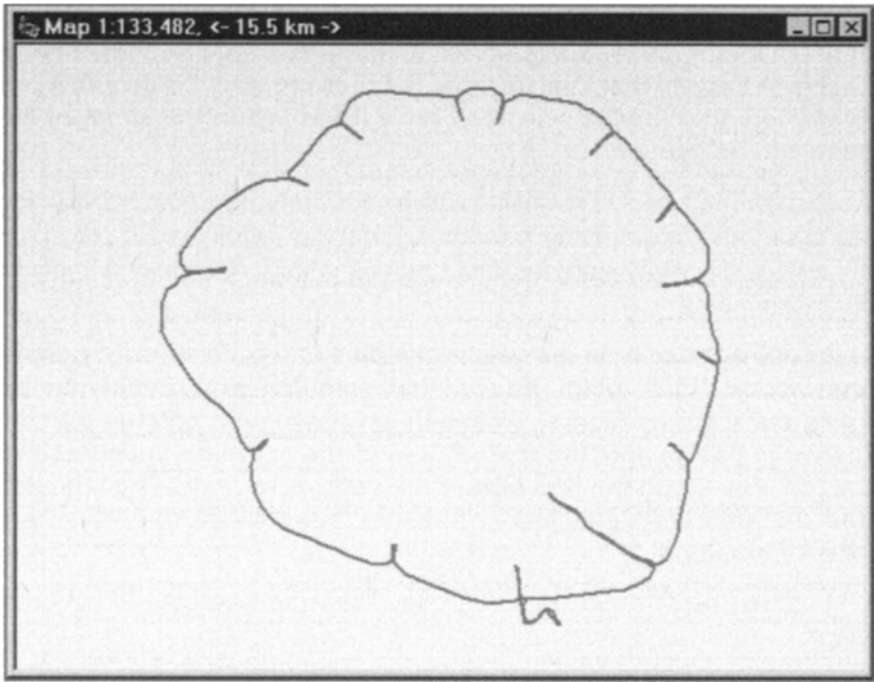
Figure 3–7. GPS track around New Circle Road.

the files NEWCIRCLE.COR and NEWCIRCLE.SSF by clicking on them in that order (with the Ctrl key held down to select the second one). Set up Layers in View so that Line_generic features are shown with a thin red line. (Note that the file selected first is listed last in the string of file names to be opened.)

NEWCIRCLE.COR is a file to which corrections have been applied; the process is described in detail in Chapter 4. But it is instructive for you to see the results, especially since the data you took in Project 2B may turn out to be disappointing.

{__} Zoom up again on the southern area and use Position Properties to select the "First" point. Be sure that Auto Pan is on. Begin moving along the trace as before. To see the improvement created by correcting the data, note the unevenness of the gray line, compared to the red one, along the first part of the path. Also

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[17] The term "corrected" is in wide use among GPS professionals. Actually, it would probably better to say the positions have been "adjusted" to become more accurate.

notice the little de-tour the gray line takes just prior to the point where the car enters New Circle Road.

{__} Under the File menu click Close. The map window will become blank.

PROJECT 3D—SA Goes Away—Background FilesHelp You See It

On 1 May 2000 the White House suddenly announced that selective availability (SA) would be turned off. The transition took place just after midnight Eastern Daylight Time on Tuesday 2 May 2000. Closer to home, a file was created using a Geo3, with the antenna at a fixed location, from about 11:30 P.M. on 1 May until about 12:30 A.M. on 2 May. The files BEFORE.SSF and AFTER.SSF were created by dividing that file with the Record Editor—a Pathfinder Office Utility Program that will be described shortly. The point of division was the time at which SA was turned off.

{__} Make a Project named ByeByeSA_yis. Have it refer to __: \GPS2GIS\ByeByeSA.

{__} Set the Time Zone to Eastern Daylight.

{__} Starting with File ~ Open, examine the contents of the folder ByeByeSA in __:\GPS2GIS. Open BEFORE.SSF. Note, by clicking on First and Last in the Position Properties window, that this file consists of fixes taken on May 1st, approximately between 11:30 P.M. and midnight. Measure the spread of fixes. What distance is there between the farthest apart points? _____.

You would like to contrast BEFORE.SSF with AFTER.SSF. We could open these two files together but since they are both Not In Feature files it would be hard to see them distinctly as separate. We would like to see them with different symbolization so we could compare them. As before, we could make one a Line_Generic file, but let's examine another way. Pathfinder Office allows you to display a file in the "background"—that is, the visual aspects of the file appears in the Map window, but no features in the file are selectable. We will use this "background" ability to display the file AFTER.SSF.

{__} ***Using the Units and Coordinate System choices under theOptions menu, set up the proper parameters for this project:*** Set the Options to U.S. State Plane 1983 coordinate system, Kentucky North Zone (1601). The datum is NAD 1983

(Conus). The Distance units and Coordinate units are Survey Feet. The Time Zone remains Eastern Daylight.

{__} Using View ~ Layers ~ Features make Not In Feature data appear as a thin red line.

{__} Using File ~ Background, check to see if any files are in the list of background files to load. Highlight any such file identifiers and click Remove to empty the window. Now click "Add" and navigate to __:\GPS2GIS\ByeByeSA\AFTER.SSF and pounce on it. Okay the Load Background Files window. Under View ~ Layers ~ Background, choose a moderately thin green line to represent Not In Feature data. Once it loads you should see a green blob surrounded by red lines. Zoom up on the green area and measure the spread of fixes. _____. Quite an improvement!

An Aerial Photo That Can Be Used as a Map:The Digital Orthophoto

A **digital orthophoto** image is an **aerial photograph,** in digital form, with a very useful special property: It has been calibrated so that it may be used as a map; the coordinates of the map are precisely specified. As you may know, most aerial photographs, even when taken with the camera pointed vertically downward, have considerable distortion, due to several factors such as uneven terrain and lens distortion. Thus, if you measure a length on a conventional photograph that corresponds to a distance on the ground, an identical length measured elsewhere on the photograph usually will not correspond to the same distance on the ground. Said concisely, a standard aerial photograph does not have a consistent scale. In a digital orthophoto image, however, objects shown on the photograph **at ground level** are related by a points on objects **above** ground level (for example, on the roofs of buildconsistent scale, even if the terrain is dramatically uneven. (The locations of ings) are ***not,*** however, shown in their correct locations.)

Digital orthophotos may come in many forms. The one we look at here is called a **"tiff"** (which stands for **"tagged image file format**.") Pathfinder Office has the capability of displaying such files as background files. The extension of tiff names is usually **"tif."** If a tiff file is keyed to a geographical location it may be called a **"geotiff";** geotiffs contain the parameters to anchor the image to the proper points on the earth's surface. If a tiff image is keyed to a geographic location but contains no geographic

parameters then it must be accompanied by a **world file;** world files usually end in the extension "tfw." Pathfinder office requires that a tiff be a nongeotiff and that it be accompanied by a world file.[18]

In the directory ByeByeSA are the following files:

No_sa_ncr_doq.tif—a tagged image file—the special kind of digitized aerial photograph that can be used as a map, showing the highway the automobile was traveling at the time of transition. The term **DOQ** in the name stands for digital ortho quadrangle; quadrangle is just another term for an "almost rectangular" map.[19]

No_sa_ncr_doq.tfw—the "world file" for No_sa_ncr_doq.tif containing numeric parameters that tell Pathfinder Office where to place the image No_sa_ncr_doq.tif.

NoSA_Moving.SSF—a subset of a file taken in a moving automobile covering the minutes of transition when SA was discontinued.

{__} Open __:\GPS2GIS\ByeByeSA\NoSA_Moving.SSF. Represent the file with a medium yellow line. Set the Time Zone to Eastern Daylight. Bring up the time line and note the time span of the file. If you look at Position Properties you will note that a number of fixes have been deleted. The idea was to capture just the time surrounding the transition.

{__} *Prepare the map of the GPS track so that the digital orthophotowill be properly positioned:* Before the aerial image can be displayed the geographic parameters of the map must be properly set. The DOQQQQ[20] (stands for digital ortho quarter quarter quarter quadrangle—since it is one sixty-fourth of a standard USGS 7.5 minute quadrangle) is in the U.S. State Plane 1983 coordinate system, Kentucky North Zone (1601). The datum is NAD 1983 (Conus). The coordinate units, altitude units, and distance units are Survey Feet. Using the Units and Coordinate System choices under the Options menu, make sure these parameters are set up correctly.

{__} *Bring up a digital orthophoto image as a background to thefiles you have selected:* From the File menu select

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[18] A geotiff may be separated into a vanilla tiff and a world file. One way to do this is with the ArcInfo CONVERTIMAGE command.

[19] We say "almost rectangular" because quadrangles frequently follow lines of latitude and longitude; depending on the projection they are in, the sides may not be straight.

Background. In the Load Background Files window remove any files that show up and then click Add. The window that appears (Add Background Files) might or might not represent the folder __: \GPS2GIS\ByeByeSA. (If it doesn't, navigate to that folder.) Select the file no_sa_ncr_doq.tif and click on Open. Read and okay a reminder if it shows up. Back in the Load Background Files window review the System, Zone, and Datum specifications. It probably appears that all is well, but it may not be. Click on Change to examine and correct parameters so they match the ones given in the previous step. Be particularly careful regarding Coordinate Units. In Kentucky they are in Survey Feet! Okay the Coordinate System window. Okay the Load Background Files window. An image should appear in the Map window.

{__} Make the main Pathfinder Office window occupy the full screen. Make the Map window wide as in Figure 3–8, so you can have Position Properties and Time Line up also. Zoom up on the part of the yellow track that crosses the DOQ. Look at the GPS tracks that represent the part of the trip on the divided highway that took place during the transition from "SA on" to "SA off." First the track, coming from the west, is way off the road, then you see some jagged spikes that occurred probably due to the transition, and finally the trace is at least in the right-of-way of the highway. With Position properties you can ascertain that the transition was completed at about 13 seconds after 12:01 AM on 2 May 2000.

PROJECT 3E—Your Data

Now that you have a good idea of how to use Pathfinder Office to display and analyze data taken with a GPS receiver, use this knowledge on the data you collected over a fixed point in Chapter 2. (If you don't have your own data use the ROOFTOP file B022721 A.SSF and settings from PROJECT 3B.)

{__} Before beginning the computer work:

• Unless your instructor tells you otherwise, you must use the machine onto which you loaded your Chapter 2 data;

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[20] DOQQQQ—this is the author's name for it. You won't find this anywhere official. You will find DOQQ (Digital Ortho Quarter Quadrangle) since the USGS markets them as a quarter of a standard 7.5 minute quadrangle. But now the most usual description is DOQ, for digital ortho quadrangle.

Figure 3–8. Watch selective availability go away.

• Recall the name of the Project to which you transferred your data. It is probably DATA_yis (where "yis" indicates your initials). The folder in which you will work is __:\GPS2GIS\ DATA_yis.
• Bring with you the full name(s) of the file(s) you collected. Also have with you the values you calculated by hand in Project 1C.
• Bring the detailed map(s) of the area(s) where you took the data so you can compare what appears on the screen with the features shown on the map.

{__} If necessary, start the Pathfinder Office software. Select Projects in the File menu. Make sure that the Project name is "DATA_yis." Click on the Open Folder icon on the Project toolbar. Click the "Details" button to see the dates on the files and folders. Review the files that are there to be sure that you are in the right folder. You should see a Backup, Base, and Export folder as well as your files. Select, with a single click, the first of the files you took. Look at the information about that file at the bottom of the window. Close the window without opening the file.

{__} Examine the map you used in Project 2A to determine the correct units, coordinate system, and datum to use. Set up the software with these parameters.

{__} Under File ~ Open, select the data file you uploaded in Chapter 2 that corresponds to Project 2A. Under View ~ Layers ~ Features, set it up to display with a green line, with the points joined. From the Standard toolbar, click Map and Time Line.

{__} The representation now on the screen should be of the points (fixes) you collected, connected in the time order in which they were logged by the receiver.

The following steps assume that you took point data in Chapter 1 and Chapter 2 in the same place.

{__} In Chapter 1 you collected data by pencil and paper, averaged the values, and wrote down the results. You set the GeoExplorer rover options before that session according to:

- Coordinates ~ Deg & Minutes (and decimal fractional parts thereof)
- Datum: (set to your map)
- Units ~ Custom ~ Distance: (set to your map)
- Units ~ Custom ~ Altitude Units: (set to your map)
- Units ~ Custom ~ Altitude Reference: Geoid (MSL)
- Date & Time ~ Set Local Time: (adjust to local time)

Set the Pathfinder Office options to the equivalents.

{__} Select Position Properties. Click on a fix that is toward the middle of the cluster of points. Read its location at the bottom of the screen and write it down here.

- Latitude _____
- Longitude _____
- Altitude _____

Is it about where you expected it to be? Compare its coordinate values against the averaged values in PROJECT 1C that you wrote down at that time.

We could make a Point_generic file (average all the fixes into a single point) as we did in Project 3B, but let's look at another way of getting the average. The data collected by the GPS receiver and downloaded into the machine take the form of **records,** which are numbered strings of text. A given GPS file will have quite a few records—at least one for every fix taken, and usually a lot more. You can look at these records with a Trimble Utility called the SSF Record Editor. When the Record Editor is invoked it automatically averages the coordinates of all the fixes and appends additional

statistical records to the file at the end. In the step below you will open the file in the Record Editor, look briefly at a few records, and then read the coordinates of the "average" point.

{__} Go into the file menu and pick "Close" to close the current file. (The Record Editor will not calculate statistics on a file if the file is open.) You have already set up the proper parameters of datum, coordinate system, and units. In the Utilities menu select Other, then SSF Record Editor. The appropriate window will come up. Under File *in that window* click Open. You should then be able to select the file you have been working with from the window that shows up. Click Open. Make the SSF Record Editor window occupy the full screen.

The resulting window is divided into two parts. (You can vary the position of the dividing line between them by dragging it with the mouse; "Split" in the View menu also works.) In the top part are the records of the file, beginning with a header record whose three letter designation is HDR. The HDR record is highlighted. In the lower part of the window are details in a more readable format relating to that highlighted record. Also, some records, like HDR, contain information not shown on the upper part of the window. This information appears in the bottom portion of the window. Make sure that the bottom part of the window is large enough to see all the text lines. Please see Figure 3–9.

Most SSF files have several types of records. Shortly you will see that toward the middle of the file you will find position (POS) records that tell you the time and position of each separate fix. At the end of the file are statistics records (STS).

{__} Look at the information in the HDR record. Then use the down arrow key and/or Page Down to look at records further down in the file. Finally, drag the vertical slider to the bottom so that the STS records that were added to the end of the file show up. Use the "up arrow" key to select the "Latitude Stat" record. Write the coordinates of that and the following records here.

- Mean Latitude ————————
- Mean Longitude: ——————————
- Mean Altitude:[21] —————————

{__} From the File menu exit the SSF Record Editor.

{__} Some of the questions below have several blanks. Assuming you took data for both PROJECT 1B and PROJECT 2A in the same location, record the calculations you made in PROJECT 1C.
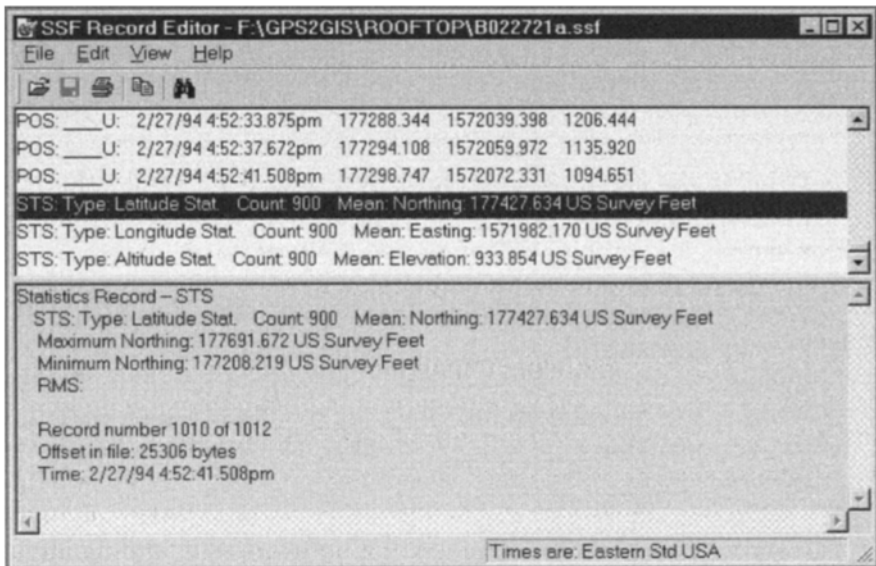
Figure 3–9. Finding statistics from the Record Editor.

Compare them with the averaged position you just found in PROJECT 2A.

• What is the average latitude in PROJECT 2A (from the Record Editor)? _____ (What was your Project 1 answer? _____) What is the difference in meters?

• What is the average longitude?_____ (What was your Project 1 answer? _____) What is the difference in meters? _____

• What is the average altitude?_____ (What was your Project 1 answer? _____) What is the difference in meters? _____

{__} Compare the position given by the software with the location presented by the map. Do they agree? Answer "yes" if the

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[21] At the time of this writing, Pathfinder Office 2.70 did not correctly calculate the altitude when the option "Measure Altitude from MSL" was in effect. If the altitude seems incorrect, it may be the altitude based on Height Above Ellipsoid. You could correct this by hand since you know (from a calculation in Chapter 1) the difference between HAE and MSL in your area.

horizontal measurement is within about 5 meters or so of the true location horizontally, and about 12 meters vertically. _____

{__} Set up the datum, coordinate system, and units to correspond to those of the map you used in PROJECT 2B (where you moved the antenna along a path).

{__} Bring in the file of PROJECT 2B and display the path you took while moving the antenna. Now query various points on the display and compare their coordinates with those on the map. Does the display correspond to the actual path you took?

{__} Add the file that contains the fixes you collected in PROJECT 2A. Are the two sites in the correct relative position? If not, you may be using different projections, different datums, or different coordinate systems.

Exercises

Exercise 3–1: Use the file __:\GPS2GIS\EXERCISE_CH3 \EXER3–1U.SSF to determine the general area it represents. Now add the file EXER3–1S.SSF as well. The beginning and end of these files are in the vicinities of two major universities on the North American continent. Which ones?

Exercise 3–2: Display EXER3–2H.SSF using dots not joined together. What town does the westernmost end of this path represent? (Think "liqueur.")

Now open EXER3–2N.SSF. What general area is represented? Add EXER3–2S.SSF (the N and S stand for North and South. Note that you may display these two files together—even though they were taken at different times.

Now add EXER3–2O. (That's an alphabetic "O.") Zoom up on this last track. What major U.S. city would you expect to find on this circuit? Change from dots unjoined to dots joined. Notice how that can confuse things.

Exercise 3–3: File EXER3–3S.SSF was generated on a sailboat that went under a bridge. A second file, EXER3–3C.SSF, was generated by a car driving over the bridge. Where did all this take place? What are the latitude and longitude coordinates of the point where the paths of the boat and car cross (use the WGS84 datum)? What is the name of the bridge? What is the name of the body of water? What major U.S. Air Force base is nearby? When you add file EXER3–3T.SSF, what major city is indicated?

Exercise 3–4: The number of the UTM zone that contains a geographic point depends on the longitude of the point. (The

longitude for a point in the western hemisphere is a negative number. That is, 100.5° West Longitude is **–100.5°,** so you would use this **negative number** in the formula below.)

To calculate the UTM zone for the western hemisphere: calculate (180°+Longitude)/6° and round the resulting quotient up to the next integer.

To calculate the UTM zone for the eastern hemisphere: calculate (Longitude/6°)+30° and round the resulting quotient up to the next integer.

(a) Find the UTM zone for Latitude 83.5° North, Longitude 100.5° West.
(b) Find the UTM zone for Latitude 35.3° North, Longitude 136.5° East.

Exercise 3–5: A **waypoint** is a 3-D point that has a name. Waypoints are used for navigation (for example, they may be the locations of radio-navigation antennas) or to mark the positions of objects. They may be generated directly by the Pathfinder Office Software and loaded into a GeoExplorer or Geo3. Or a GPS receiver may calculate a waypoint from satellite data, or have a waypoint specified using the buttons on the front of the datalogger. However or wherever it is, a waypoint consists of a name and a location. Like other geographical data, the numerical descriptions of the position of the point may be specified in any of several coordinate systems.

The point of this exercise, besides being the briefest introduction to way points, is to show you what a difference the selection of a geographic projection can make in graphical presentation of data. In Pathfinder Office close any open files. Make sure the Map window is open. Set the coordinate system to Latitude and Longitude. Set the Distance Units to meters. Under View ~ Layers ~ Waypoints pick a blue diamond. Now select File ~ Waypoints ~ Open and navigate to __:\GPS2GIS\EXERCISE_CH3 \lat_lon_square_ north.wpt. Pounce on that file name. A map of four waypoints should be displayed as should a window named Waypoint Properties that names and describes the waypoints in the wpt file. (If the Waypoint Properties window doesn't open you can click the appropriate icon on the toolbar or place a check beside Waypoint Properties in the Data menu.)

Notice from the Waypoint Properties window that the four waypoints (named NW, SW, SE, and NE) form a "square" (in terms of lat-lon coordinates) whose lower left (SouthWest) corner is at 83° N and 101 °W and upper right corner (NE) is at 84°N and 100°W. If you measured the distance between adjacent waypoints with a ruler on the computer screen, you would verify that they geometrically form a square. If you use the Data ~ Measure tool, however, you find that there is a much greater distance between the points that line up vertically than those that line up horizontally. (I deliberately picked locations in the far north to demonstrate the differences in measurements of latitude and measurements of longitude.) What is the north-south difference in meters? _____ What is the east-west difference in meters between the northernmost waypoints? _____ Further, there is a difference of about 2000 meters between the pair of northernmost waypoints and the southernmost ones. Which pair is further apart? _____.

To see how showing a map in latitude and longitude distorted the distances, change the coordinate system to UTM where you will get a more satisfying presentation. (What you will see initially may look pretty strange— since you haven't set the UTM zone. Set it to the Zone you calculated in Exercise 3–4 for latitude 83.5° North, longitude 100.5° West.)[22] What you should see now is approximately a skinny trapezoid, with the top side imperceptibly shorter than the bottom side. Again you could measure the distances with the measuring tool. You should get the same values as before, despite the radically different visual portrayal.

More Exercises: In the folder __:\GPS2GIS \Exercises_and_Exams are a great many SSF files taken from locations in several parts of the world. See Appendix B for a form that you may complete. The form asks you to determine the location or track of the receiver antenna. How many points were taken? Over what time period? Would you say the antenna was at a fixed point or moving? If moving, how fast on the average? Was

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[22] Future versions of Pathfinder Office may calculate the UTM Zone automatically from the latitude and longitude coordinates.

there much change in the altitude? Were these changes likely due to errors (remember SA was eliminated on 2 May 2000) or to an actual change in altitude?

4
Differential Correction

IN WHICH we take a closer look at the subject of GPS accuracy and explore techniques that reduce errors.

OVERVIEW

GPS Accuracy in General

When you record a single position with a good GPS receiver, the position recorded will probably be within 5 to 15 meters horizontally of the true location of the antenna.

When a surveyor uses good, survey-grade GPS equipment he or she can locate a point to within a centimeter of its true horizontal position. What are the factors that allow the surveyor to be 1,000 or so times more accurate than you are? This is a complicated subject. The answer includes "very good equipment," "measuring the actual number of waves in the carrier" (as differentiated from interpreting the codes impressed on the carrier), and "spending a lot of time" at each site.[1] We can cover only the basics in a book of this scope. But you will learn how to reduce errors so that you can record a fix to within half a meter to three meters of its true location. One primary method of gaining such accuracy is called "differential correction."

Differential Correction in Summary

In a nutshell, the differential correction process consists of setting a GPS receiver (called a **base station**) at a precisely known geographic point. Since the base station knows exactly where its antenna is, it can analyze and record errors in the GPS signals it receives—signals that try to tell it that it is somewhere else. That

is, the base station knows the truth, so it can assess the lies being told to it by the GPS signals. These signal errors will be almost equivalent to the signal errors affecting other GPS receivers in the local area, so the accuracy of locations calculated by those other receivers may be improved, dramatically, by information supplied by the base station.

Thinking about Error

For the logging of a given point, define **"error"** as the distance between what your GPS receiver **records as the position** of the antenna and the **trueposition** of the antenna.

It is useful to dissect the idea of "error." We can speak of error in a horizontal plane and differentiate it from the vertical error. This is important in GPS, because the geometry of the satellites almost always dictates that no matter what we do, vertical error will almost always exceed horizontal error on or near the surface of the earth. The fact that all the satellites are necessarily above the fix being taken generally means that vertical error will be 1.5 to 2.5 as great as horizontal error.

Another useful distinction is between what we might call **random** error and **systematic** error, or bias. Random errors are deviations from a "true" value that follow no predictable pattern. Systematic errors do follow a predictable pattern. An example will be illustrative. Suppose we have a machine designed to hurl tennis balls so that they land a certain distance away on a small target painted on the ground. Of course, none of the balls will hit the center of the target exactly; there will always be some error.

What factors might cause errors? The balls are each of slightly different weight; they are not symmetrical and will be loaded into the machine in different orientations. Since it is hard to determine the effects of these factors on the accuracy of the process, we say the factors induce random errors. If there are only random errors in the process, some balls will hit short of the center of the target, some beyond it, some left, some right, and so on. If we shoot 100 balls from the machine we will see a pattern of strikes in the area of target which appears somewhat random, but which clusters around the target.

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[1] A sarcastic surveyor of the author's acquaintance said that GPS for surveyors stood for Get Paid for Sitting.

Now suppose that we had set up our machine and its target when there was no wind, but then a constant breeze of 10 miles per hour began blowing from the right across the path of flight of the tennis balls. This would create a systematic error: each ball would land somewhat to the left of where it would have landed in the no-wind condition. We will still see a random pattern of hits, but the average of all hits will be somewhat to the left of the target. This is systematic error; the "system," including the wind, causes it. To correct, we could aim the machine somewhat to the right.

Other examples of factors that might contribute to errors are: as the temperature changes, the characteristics of the machine may change; the atmospheric pressure and the relative humidity of the air will affect the drag on a ball; and so on. Whether these might be random errors or systematic ones might be hard to determine.

Generally, random errors are those caused by factors we cannot measure or control; systematic errors are those we can account for, measure, and, perhaps, correct for.

First Line of Defense against Error: Averaging

When I implied that the surveyor could be 1,000 times more accurate than the average person with a GPS receiver, I was being somewhat disingenuous, mostly for effect. I was comparing a single reading with inexpensive equipment with the average of many readings from expensive equipment. This is not a fair contrast, since you can improve the accuracy of the less expensive equipment by taking many readings at a fixed point. You recall that the strikes of the tennis balls, with no wind, tended to cluster around the target. GPS readings tend to cluster around the true location. We can use the fact that large numbers of random errors tend to be self-canceling. That is, the average position (if you take the means of many latitudes, of many longitudes, of many altitudes) will be much closer to the true value than the typical single measurement.

One measure of accuracy of GPS fixes is called Circular Error Probable (CEP). It is the radius of a circle expressed in a linear unit, such as meters. For a given situation, 50% of the fixes will fall within the circle, and 50% outside. Another measure of accuracy is based on two standard deviations of a normal distribution—called 2dRMS where RMS means root-mean-square.

Ninety-five percent of the fixes will lie within a circle with this radius.

For NAVSTAR GPS, a number of experiments suggest that 50% of the latitude and longitude fixes you obtain with a single receiver operating by itself (i.e., autonomously) will lie within 12 meters of the true point. Fifty percent of the altitude fixes will lie within 21 meters. The 2dRMS radius is 30 meters horizontally, and 70 meters vertically. These numbers assume that selective availability is off.

In general, the more fixes you take and the more time you spend, the better your average will be. If you are prepared to take data at one point for several weeks to several months your error will get down to approximately one to two meters, basically due to the law of large numbers.[2] This may not be a practical way to reduce error in most applications.

Another approach, which is related to averaging in a different way, is to use "over-determined" position finding. As you know, four satellites are required for a 3-D fix. But suppose your receiver has access to five or more at a given time. Each set of four of the satellites available will provide a different opinion on the position of the point being sought. A compromise agreement based on all the satellites' input is probably better than the position indicated by any one set of four. The GeoExplorer may be set to collect data in this way.

Sources of GPS Error

Now look at the specific sources of errors in GPS measurements. Typical error sources and values for receivers of the Pathfinder class are:

satellite clocks	<1 meter
ephemeris error	<1 meter
receiver error	<2 meters
ionospheric	<2 meters
tropospheric	<2 meters
multipath	(depends on the situation and the receiver; may be large)

These values correspond to averages of many readings rather than the error that might be expected from a single reading. Although experimentation shows that the more fixes you record the better

the data become, the increase in accuracy created by taking a large number of fixes really cannot be counted upon. The existence of systematic errors that might be present because of particular atmospheric conditions (or, for certain, when selective availability was active) makes the law of large numbers inapplicable. As you will see shortly, there are better ways to get really accurate data. And much more accurate data are almost always required when using GPS for GIS purposes.

Clock Errors

As you know, the ability of a GPS receiver to determine a fix depends on its ability to determine how long it takes a signal to get from the satellite to the receiver antenna. This requires that the atomic clocks in the satellite be synchronized. Even a small amount of difference in the clocks can make a huge difference in the distance measurements, because the GPS signal travels at about 300,000,000 meters per second.

Ephemeris Errors

The receiver expects each satellite to be at a certain place at a particular given time. Every hour or so, in its data message, the satellite tells the receiver where it is predicted to be at time "t" hence. If this ephemeris prediction is incorrect—the satellite isn't where it is expected to be, even by just a meter or two—then the measurement of the range from the receiver antenna to the satellite will be incorrect.

Receiver Errors

These errors result from a number of factors related to receiver design, cost, and quality. Some receivers, for example, cannot exactly measure and compute the distance to each satellite simultaneously. The GeoExplorer can track up to six satellites at a single moment; it is a six-channel receiver. In any receiver the computer must work with a fixed number of digits and is therefore subject to calculation errors. The fact is, perfection in position calculation by computer simply is not possible, because computers

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[2] According to Chuck Gilbert, of Trimble Navigation, writing in the February 1995 issue of *Earth Observation Magazine*.

cannot do arithmetic on fractions exactly. (It is true that other computer operations, such as addition of integers, are perfect.)

Atmospheric Errors

For most of its trip from the satellite to the receiver antenna, the GPS signal enjoys a trip through the virtual vacuum of "empty space." Half of the mass of the earth's atmosphere is within 3.5 miles of sea level. Virtually all of it is within 100 miles of the surface. So the signal gets to go the speed limit for electromagnetic radiation for more than 12,000 of the more than 12,600 miles of the trip. When it gets to the earth's atmosphere, however, the speed drops very slightly—by an amount that varies somewhat randomly. Of course, since the calculation of the range to the satellite depends on the speed of the signal, a change in signal speed implies an error in distance, which produces an error in position finding.

Significant changes in signal speed occur throughout the atmosphere, but the primary contributions to error come from the ionosphere, which contains charged particles under the influence of the earth's magnetic field, and from the troposphere—that dense part of the atmosphere that we breath, that rains on us, and that demonstrates large variations in pressure and depth.

More sophisticated GPS equipment can "calculate out" most of the ionospheric error because it considers both the frequencies transmitted by each satellite. Since the ionosphere affects the different frequencies differently a correction can be calculated. Tropospheric errors, however, we seem to be pretty much stuck with, especially using the moderately inexpensive code-based equipment available to civilians. This will change when a second civilian signal is added to the system.

Multipath Errors

As indicated in Chapter 2, substantial errors may occur if a given radio signal follows two paths to the receiver antenna. This can happen if a part of the signal is bounced off an object, such as a building. The arrival of two or more parts of the signal at different times can confuse the receiver and produce a false reading. Many receivers are programmed to disregard the second signal. But a problem can occur if the direct signal is blocked but the related bounced signal is seen by the antenna and recorded.

Selective Availability—A Former (We Hope) Source of Error

Until May 2, 2000 the lion's share of the "Error Budget" came from deliberate corruption of the signal by the U.S. Department of Defense (DoD). As I have said, they didn't want the civilian GPS receiver to be able to pinpoint its position. In fact, in the early days, they didn't want the civilian world to know GPS existed. Selective availability was one technique the military could use to keep the system from being too accurate. (Another is called "antispoofing.") The errors were probably induced by dithering (making inaccurate) the signal that tells the ground receiver the exact time or by broadcasting a slightly false ephemeris. Obviously, the military didn't want to say too much about its techniques for making the good GPS signals "selectively available"—i.e., available only to military receivers.

The DoD had, on occasion, turned selective availability off before. (Two notable times were during the Mideast War with Iraq and during the almost-invasion of Haiti.)

With SA off an autonomous receiver can supply much more accurate position information. The 50% measure (CEP) measure is about 12 meters horizontally and 21 meters vertically, due to the errors previously discussed. Ninety-five percent (2dRMS) of the fixes fall within 30 meters horizontally, and 52 meters vertically.

Reducing Errors

As it turns out, most of these errors can be "calculated out" of the measurements by the process called differential correction. To understand how it works, let me first show you the results of an experiment.

Figure 4–1[3] shows two sequences of points (two different files) taken with a GeoExplorer receiver placed at a single location, operating during two different time periods.

The neat string at right was made of fixes taken about 6 seconds apart; the mess at the left was measured by taking points every 20 seconds during a different time period. (The tick marks are 10 meters apart.) You should realize that each and every fix here is attempting to approximate the same true position. They show up in different positions because of the errors discussed above. We don't know what the true position of the antenna was, but almost certainly each point misses the exact, true position by some amount.
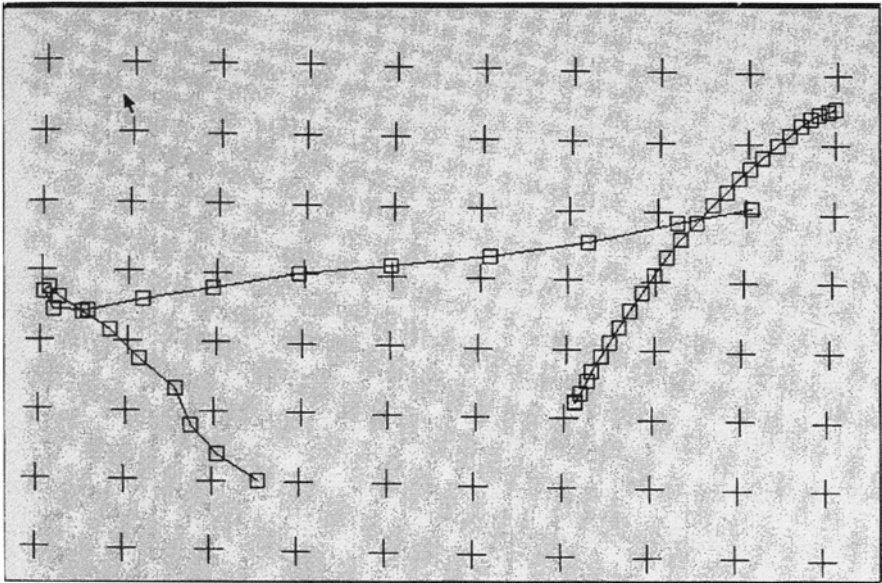
Figure 4–1. Two files of the same point data (GeoExplorer).

Figure 4–2 shows data collected at the same times as in the previous figure; the computations of location were based on the same set of four satellites. The antenna for this receiver (a Pathfinder Basic) was in virtually the same geographic location as the other.

Now look at a composite of the two sets of data as shown in Figure 4–3. The points of the GeoExplorer data are marked with boxes; the Pathfinder data are marked with circles.

What is interesting is that the two patterns of fixes show remarkable similarity. Pairs of fixes—taken at the same time from the same set of satellites—appear in about the same position. This suggests that the *error* for each associated pair of points is almost identical, even though the fixes have come from different receivers and different antennas. And this suggests something which turns out to be true, though I have not proved it here: that receivers calculating from the same signals will suffer from almost the same errors, provided that the antennas are "close." What's close? Two receivers within
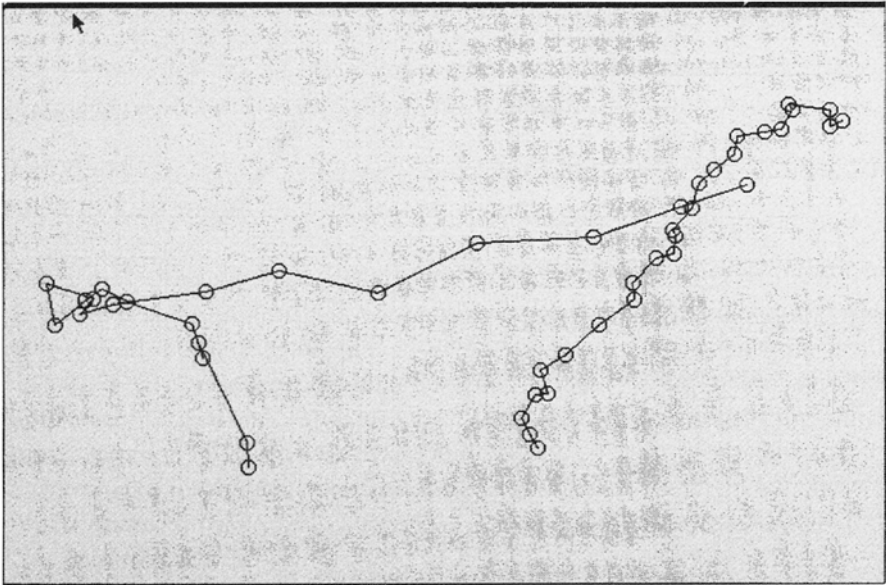
Figure 4–2. Same point as previous figure (Pathfinder Basic).

500 kilometers (300 miles) will tend to show the same magnitude and direction of errors with respect to the true locations of their antennas, provided the positions are found using the same set of satellites.

More Formally[4]

The experiment described above demonstrates that much of the error is inherent in the signals—that is, the errors occur before the signals reach the receiver antenna.

To see how that helps us remove most of the error from a GPS fix, let's focus on both a single point on Earth's surface (a true point, "T"), and its representation in the GPS receiver (the measured, or observed, point, "O").

Suppose we take a GPS receiver antenna, and place it precisely at that *known point* "T"—a point that has been surveyed by exacting means and whose true position is known to within a centimeter. We call such an antenna-receiver configuration **GPS**

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[3] These files were taken when selective availability (SA) was active. Files taken with SA turned off would reveal similar patterns but not as dramatically, since the amount of error has been greatly reduced.
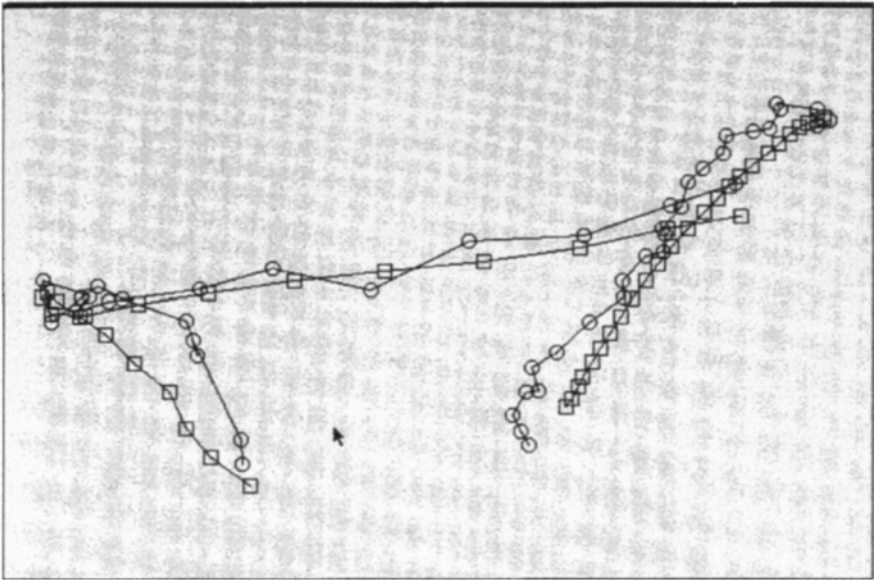
Figure 4–3. Composite of four files; same antenna locations.
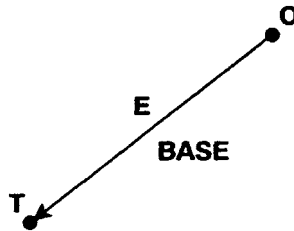
Figure 4–4. Error vector—from observed point to true point.

base station. Now consider that an observation "O" is taken by a base station receiver. So we have three entities to consider, as shown in Figure 4–4:

- the position of "T,"
- the reading "O," and
- the "difference" between "O" and "T."

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[4] This discussion provides information about the result of the differential correction process. Actual techniques are involved and varied.

We've drawn an arrow from the measured point to the true point. This arrow, which is shown in two dimensions but which would really exist in three, has both a length (called a magnitude) and a direction. An entity that has magnitude and direction is known as a **vector**. We label the vector "E," for "error," because it represents the amount and direction by which the reading missed the true point. Usually we don't know E, but here we can calculate it. The following discussion indicates how.

In general, when we have used GPS, we have used the reported coordinates, "O," as an approximation of "T." The vector "E" was the (unknown) amount by which we missed determining the position "T." As an equation we could write:

$$T = O - E$$

where we record "O" and we disregard "E" to find an approximation of "T." That is, the true coordinates are the observed coordinates minus the error. At best, we could estimate the magnitude—but not the direction—of "E." (It is important to realize that none of these quantities are **scalars** [simple numbers like 23.5] but are three-dimensional entities, so the "–" sign indicates vector subtraction. The concept we are attempting to communicate survives this complexity.)

But if we know "T" exactly, and of course we have the measured value "O," then we can rewrite the above equation to find "E":

$$E = O - T$$

What good is being able to calculate "E"? It allows us to correct the readings of *other* GPS receivers in the area that are collecting fixes at unknown points.

We demonstrated above, with Figures 4–1, 4–2, and 4–3, that if two GPS receiver antennas are close, and use the same satellites, they will perceive almost the same errors. That is, for any given point at any given moment, "E" will be almost exactly the same for both receivers. Thus, for any nearby point reported by a GPS receiver as "o," its true value "t" can be closely approximated simply by applying the equation:[5]

$$t = o - E$$

Since both "o" and "E" are known, the error is effectively subtracted out, resulting in a nearly correct value for "t," as shown by Figure 4–5.

This technique provides an opportunity for canceling out most of the error in a GPS position found by an antenna that is close to another antenna which is over a known point. As I mentioned
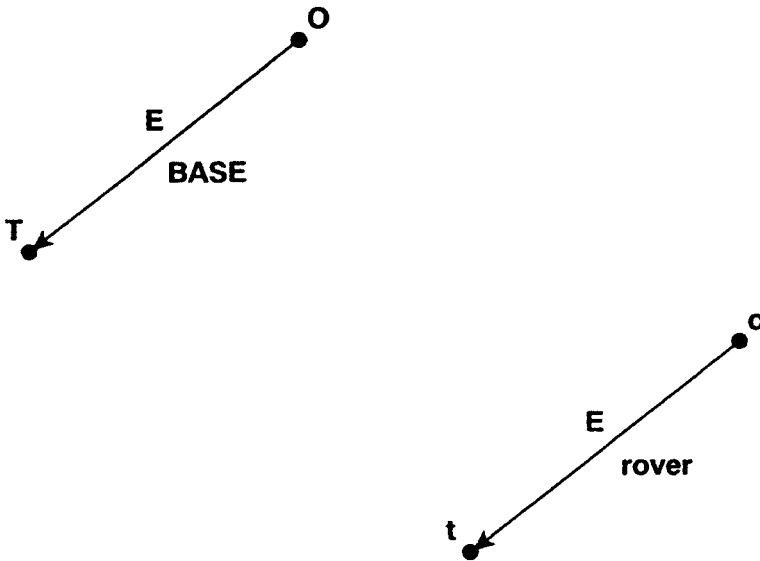
Figure 4–5. Know error vector applied to point observed by rover.

before, "close" is about 500 kilometers or 300 miles. The formula for the amount of error you might   expect with differentially corrected data is dependent on the distance between the base station antenna and the rover antenna. A rule of thumb is that the fix will be in error by one additional centimeter for each three kilometers between the two antennas. This relationship is approximately linear: 300 kilometers would produce error of about a meter.

Making Differential Correction Work

From a practical point of view, a number of conditions have to be satisfied for the process to work. The base and rover have to be taking data at the same time, and the base has to be taking data frequently. If the base station is to serve the rover, wherever it may be (within the 500 km limit), regardless of when data are taken, the base station must take data from all satellites the rover might see. This can cause a problem: if the base and rover are widely separated the rover might see a satellite that the base

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[5] Capital "O" and "T" are used to indicate base station variables; lowercase "o" and "t" indicate a rover.

Figure 4–6. Base station misses a satellite that the rover sees.

cannot view. For example, if the base and rover use the same elevation mask (say 10°), the rover might see "Satellite B" in Figure 4–6, while the base would not.

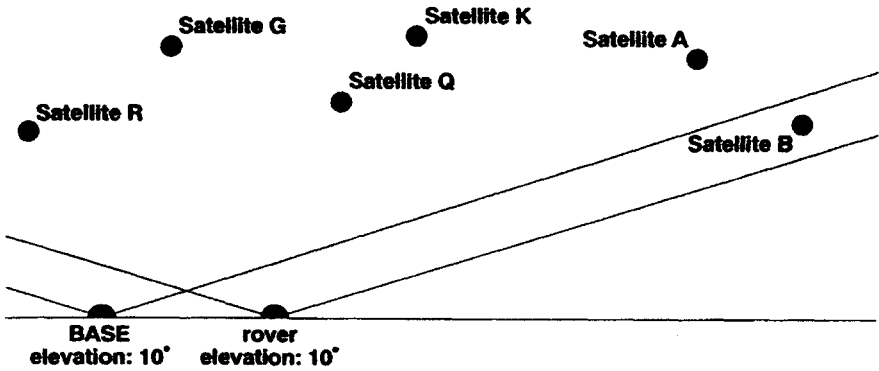Usually base stations are set up with an elevation mask value of 10°. A good rule of thumb is to increase the elevation mask for the rover by one degree for every 100 kilometers (60 miles) it is from the base station. So a setting of 15 degrees works well for the rover in general if it is within 500 km of the base station. Fifteen degrees is also good for avoiding difficulties due to terrain, and that elevation angle reduces errors that tend to occur when signals come from satellites low on the horizon, since those signals must pass through more atmosphere. In any event the rover elevation mask must be set high enough so that there is no possibility the rover will record data from a satellite that the base is not recording, as illustrated by Figure 4–7.

Correcting errors by the differential correction method implies that the base station—the receiver at the known point—can communicate with the roving receiver(s). In practice this happens either:

- at the time the readings are being taken, called Real-time Differential GPS (RDGPS), or
- after the readings from the receivers are loaded into a computer, which we call post-mission differential correction.

In RDGPS, a radio link is set up between the base station and the rover. As soon as the calculation for a given point is completed by the receivers, a rover uses the correction signal broadcast by the base station to adjust its opinion of where the point is.
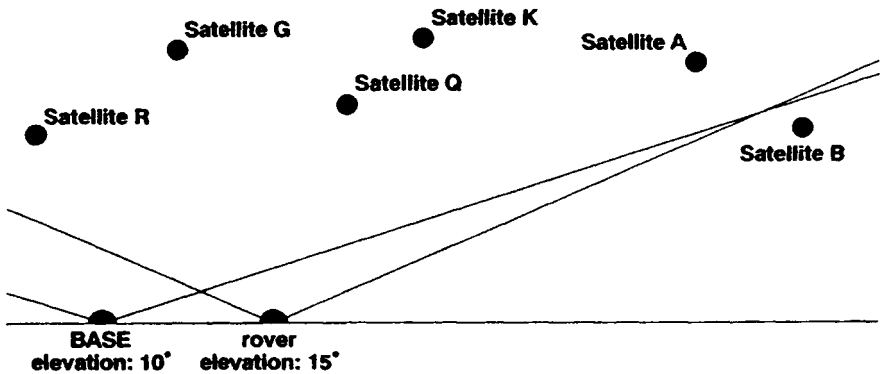
Figure 4–7. Neither base nor rover sees Satellite B.

In **postprocessing** GPS, (more correctly called **postmission-processing** GPS), the data from both the base and the rover are brought together later in a computer, and the appropriate correction is applied to each fix created by the rover. In the projects that follow, you will use postmission processing to correct GPS files. For mapping and GIS activities this approach yields better results.

Proof of the Pudding

The above discussion became pretty theoretical. Is differential correction worth it? You be the judge. The files we used to open this Overview are shown again below. But there is something additional: a "smudge" in the lower left of Figure 4–8. Here we added all the fixes that were displayed before, but here now each fix was differentially corrected. In other words, all the fixes with their obvious errors are now within the area of one small circle—that presumably includes the true location of the antennae. The ticks again are 10 meters apart, so you can get an idea of the amount of error reduction and the accuracy you can expect from differentially corrected data.[6]
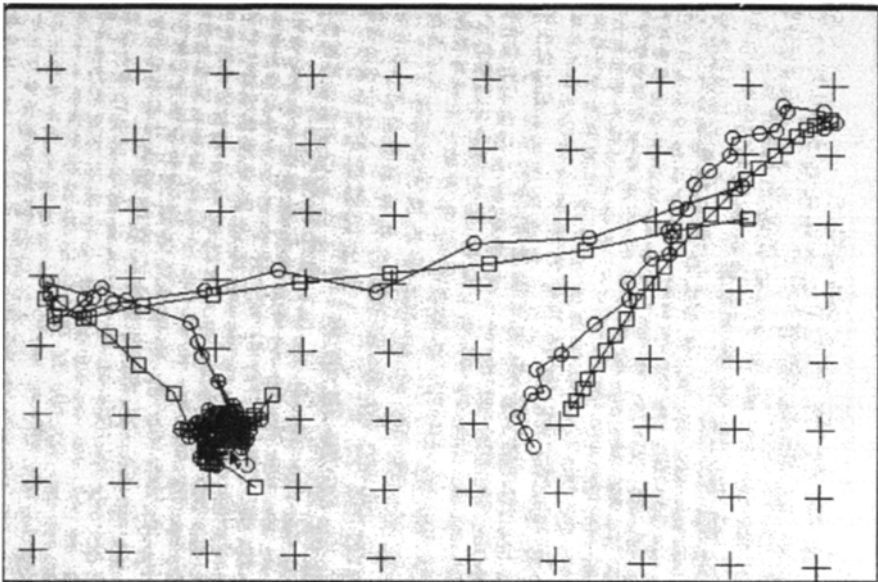
Figure 4–8. Eight files; four as collected, then as corrected.

STEP-BY-STEP

PROJECT 4A—Rooftop II

Look at the Effects of Differential Correction[7]

Before you postprocess any data yourself, you will see a demonstration of the effects of differential correction. You will consider four files:

1. An uncorrected SSF file taken with the antenna stationary. It is named T071122A.SSF and it was collected as a Not In Feature type file.

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[6] Probably the term should be "differentially adjusted data" since the resulting data still contains errors. Some of the inaccuracy has been taken out, but the results are by no means exactly "correct."

[7] Some of the files used for illustration in this chapter were generated when selective availability was still active. A contrast is provided between those files and non-SA files.

2. Each fix of the file above was modified by differential correction; the corrected file is called T071122A.COR. That file was then converted, using the Grouping Utility, to T071122A_COR_ LINE—a Line_generic file so it can be distinguished when you display it.

3. T071122A_COR_1PT: A Point_generic file consisting of a single point that is the average of the corrected fixes—that is, the average of the fixes in T071122A.COR.

{__} Start the Pathfinder Office software. If you are asked about a Project, select Default. (We won't be using the advantages of a Project in this exercise. "Project" is a convenience for pointing to a set of files and directories, but it is not necessary for the operation of Pathfinder Office. Since we will be jumping around from directory to directory, we will put aside the Project approach for the moment.) Close any open windows.

{__} Click the "Open" icon (a yellow file folder on the Standard Toolbar) and navigate so you can see the files in __:\GPS2GIS \ROOFTOP. Set "Files of Type" so you can see **All files *.*.** (I did away with the SSF and COR file extensions when I converted some files.) There you will find T071122A.SSF. Single click on the file icon. Note that the file consists of 334 observations taken within a single-hour period (using some older GPS equipment); the antenna was stationary. You will also find T071122A_COR_LINE, also consisting of 334 fixes— actually the same ones, except that each fix has been moved by a correction vector such as we described in the previous overview. Finally, the third file is called T071122A_COR_1PT. It is a single point that is the average of T071122A.COR. Open all three files. Even if the Map window is open, don't bother looking at them yet.

{__} Set the Coordinate System to (UTM, Zone 16 in the Northern Hemisphere. Set Coordinate Units to Meters. Set the Datum to WGS 1984. Set "Altitude Measured From" to MSL (EGM96 Global) in meters. Set Distance units to Meters. The time zone is Eastern Daylight.

{__} Under View ~ Layers ~ Features set the following:
(Make sure the "Join" box is checked so you get lines and not just points, which are less easily visible.)

Not In Feature: a thin gray line (for T071122A.SSF)
Line_generic: a thin green line (for T071122A_COR_LINE)
Point_generic: a red square (for T071122A_COR_1PT)

{__} Open both the Map and Time Line windows. Measure the distance of the points furthest apart on the uncorrected SSF data. You should get about 200 meters—which is consistent with the general accuracy stated for autonomous GPS readings when selective availability was active: 95% of the points fell within 100 meters of the true location.[8]

{__} Examine the trace made by the corrected data file, shown by the green lines. Notice the dramatic reduction in variation made by the correction process. Zoom up so that the corrected file fixes fill the window. Measure the distance between furthest points of the corrected data file. You should see about a five-fold improvement in the accuracy in the two dimensions shown by the map. Selective availability was active at the time this file was collected. The improvement is remarkable. Less dramatic improvements occur when SA is not active, as you will see shortly.

{__} Open the Position Properties window (use either the icon or the Data menu). Using the Select arrow pointer, click on the single point of T071122A_COR_1PT in either the Map or the Time Line window. (This is probably most easily done in the view of the Time Line.) A box should appear around the point in both the windows. If you have set all the parameters correctly, the Position Properties window should reveal the location of this average point:

4,207,347.119 meters (north of the equator) and,

720,651.532 meters (which is 220,651.532 meters east of the 87th (west) meridian, which is the central meridian of UTM Zone 16)[9]

The altitude should be 297.001 meters.

We don't know whether the found point actually lies close to the true point—since we have no data on where the antenna truly was. But in the next Project, we use a surveyed point to compare our GPS readings with.

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[8] We do not actually know the true location; we are simply inferring that it lies close to the average of the points.

[9] If this confuses you, you need to do a bit of study on the UTM coordinate system.

PROJECT 4B—The McVey Monument

Correct Some Supplied Point Data

In the steps below you are supplied with a data file of 60 fixes taken with the antenna placed over the carefully surveyed McVey National Geodetic Survey (NGS) marker located on the University of Kentucky (UK) campus.[10] You are also supplied with base files taken by Trimble community base stations. Base station files usually consist of an hour's worth of position data. A new file is started every hour, on the hour, 24 hours a day, seven days a week.

The format of a base station file is XYMMDDHH.SSF, where

- "X" is an arbitrary, permanent "prefix" letter chosen by the base station managers to identify files from that base station
- "Y" is the last digit of the year in which the base station file was collected
- "MM" is the number of month in which the base station file was collected
- "DD" is the number of the day in which the base station file was collected
- "HH" is the hour, **in UTC time,** of the day in which the base station file was collected

In general you can obtain a base station file over a computer communication network such as the Internet or its alter ego, the Worldwide Web. Another way is to download the file to your computer through anonymous **FTP (File Transfer Protocol)**. Or, you could request a base station file be sent to you through the mail on a floppy diskette if the base station does not have a web site or anonymous FTP—a situation which occurs less and less frequently. Base station files are usually large (compared to rover files)— from 150Kb to 350Kb. Sometimes, to reduce their size, and hence the time it takes to transmit them electronically, they are compressed into "ZIP" files or self-extracting "EXE" files. Base stations usually record a data fix every few seconds from all the satellites in view, using an elevation mask of 10°.

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[10] The National Geodetic Survey (NGS) is part of the National Oceanic and Atmospheric Administration (NOAA). It is the oldest scientific agency in the United States; Thomas Jefferson established it in 1807 as the Survey of the Coast.

{__} Start a new Project named McVey_NGS_yis, with the primary folder as __:\GPS2GIS\McVey_NGS. The directory structure has already been set up for you with Base, Backup, and Export folders.

{__} Close all files and windows (except Pathfinder Office, which should occupy the full screen). Bring up the Differential Correction window, either by selecting it in the Utilities menu or by clicking on the Differential Corrections icon (it looks like a target) on the Utility toolbar.

Because you have a Project selected, navigating to the proper files should be easy. Basically, to fill in the blanks of the DIFFERENTIAL CORRECTIONS window, you have to select

- the rover file(s) that you want corrected
- the base file(s) needed to do the corrections
- where the corrected file(s) are to be placed
- some parameters

{__} Under Rover Files click Browse. Navigate, if necessary, to the file C:\GPS2GIS\McVey_NGS\M032522A.SSF. (If it doesn't appear, make sure Files of Type include those files with SSF extensions.) Click on the file. Click on "Open" to okay the choice. Back in the Differential Corrections window, the choice should appear; the directory and file name should both be presented.

{__} Under Base Files click Browse. The contents of the "base" directory, located within the McVey_NGS directory, should appear, containing a set of file names of base station files. Among others you will see four files—two from each of two nearby base stations. They are:

A9032521.SSF
A9032522.SSF
L9032521.SSF
L9032522.SSF

The files that begin with "A" are from the UK Department of Agriculture. Those starting with "L" are from the Bluegrass ADD—a regional area development district. Two of these files might be appropriate for correcting M032522A.SSF. Which are they?

_____ _____

{__} Cancel the "Select Base Files" window. (We have a slicker way to get them.)
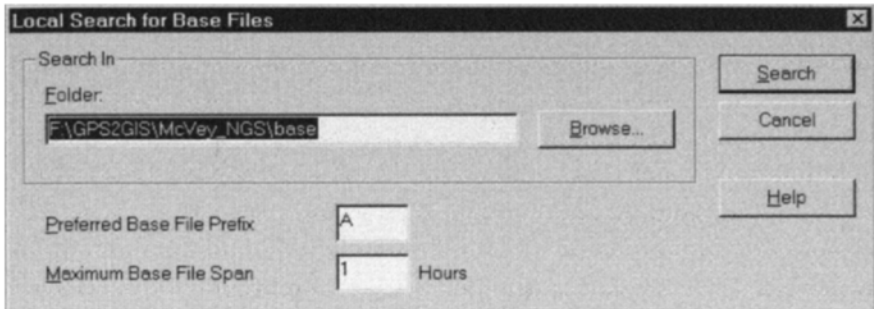
Figure 4–9. Finding differential correction files in the Base folder.

{__} Click Local Search to initiate a search of the project directory Base folder within the McVey_NGS directory. A "Local Search for Base

Files" window will appear, looking like Figure 4–9. It should show __:\GPS2GIS\ McVey_NGS\Base in the Folder text window.

{__} After making sure that the path to the directory is correct, place an "A" in the Preferred Base Station Prefix field. Then press Search.

{__} A window asking you to Confirm Selected Base Files will appear—please see Figure 4–10. Study this window. Assure yourself that the time covered by the base station file indeed includes the time period over which the rover file was taken. Then okay the window.

{__} A window showing the Reference Position of the base station will appear. See Figure 4–11. You could put in new coordinates, but you have no reason to dispute that what is shown is indeed the location of the base station antenna. You could change the coordinates, but don't. Okay the window.

{__} Check to see if the Output Folder specifies __:\GPS2GIS\ McVey_NGS and that the file extension is "COR." The name of the corrected file will be M032522A.COR. Since you will be correcting "code" data (as differentiated from "carrier" data) be sure that either "Smart Code and Carrier Phase Processing" or "Code Processing Only" is checked under Processing. Look over the Differential Corrections window; okay it if it is correct; fix it if it's not.

{__} You may get a warning that a file will be overwritten. You want to continue anyway.

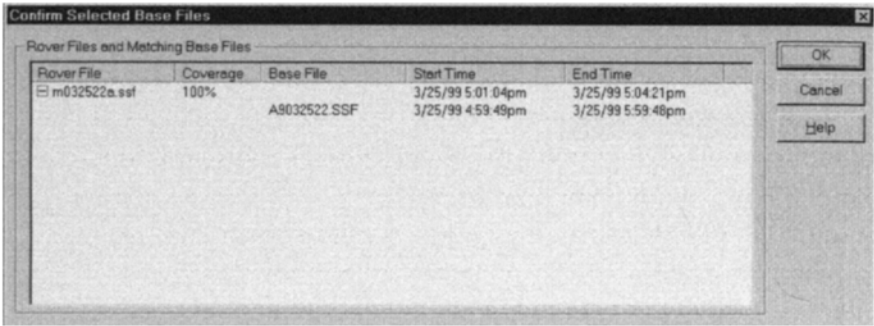**Figure 4–10.** Checking compatibility of the rover and the base station files.
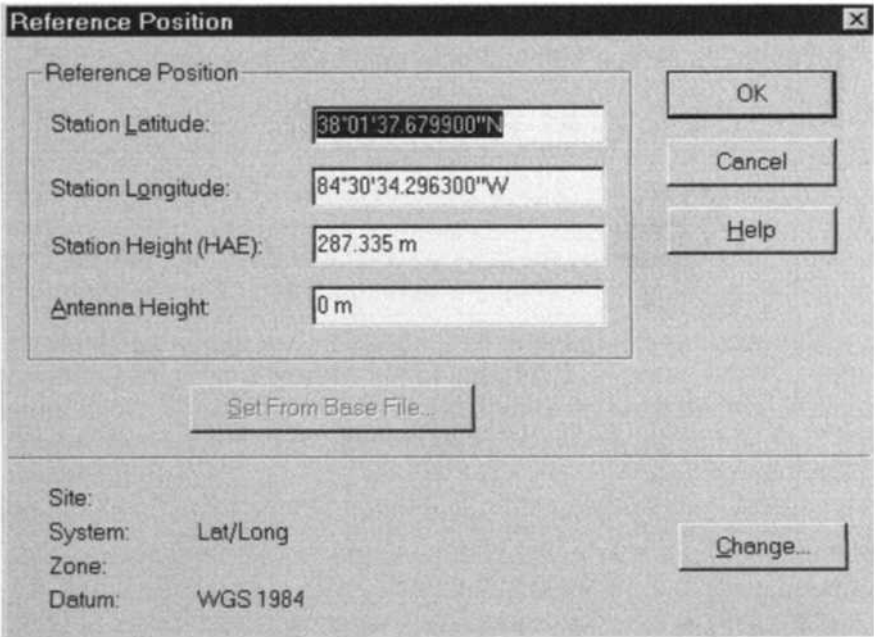

Figure 4–11. Reference position of the base station.

{__} Watch the reports of the progress of the correction process. When it is finished 60 positions should have been adjusted; ask for "More Details." Examine the resulting report, then dismiss it. Close the Differential Corrections Completed window.

Map the Data

{__} Open the files M032522A.SSF and M032522A.COR. Map them. Unfortunately you can't tell much because they are both Not in Feature files. Do you recall how to use the Grouping utility to convert a file from a Not In Feature file into a Generic_line feature file? Do you recall also how to get a Generic_point feature file that averages the 60 fixes to get the estimate of the single point? If not, use the next few steps to guide you.

{__} Start the Grouping utility. For the input file, "Browse" and choose M032522A.COR. Call the output file MV_LINE.COR. Use "One group per input file" and create the feature type **"Lines."** Okay.

{__} Start the Grouping utility again. For the input file choose M032522A.COR. Call the output file MV_POINT.COR. Use "One group per input file" and create the feature type **"Points."** Okay.

{__} Open M032522A.SSF, MV_LINE.COR, and MV_POINT.COR. If necessary, fix up the display parameters with View ~ Layers ~ Features so that you can tell the three files apart. Again, note the improvement that differential correction made. Enlarge the Map window somewhat and Zoom up on the corrected fixes.

{__} Open the Time Line window. With the arrow pointer, select MV_POINT.COR so that there is a box around it. Under Options, make the coordinate system Latitude and Longitude and the Datum NAD 1983 (Conus). The altitude units should be US Survey Feet. Make the Style of Display DD*MM'SS.ss"—that is, degrees, minutes, seconds, and decimal fractions of a second.

{__} Open the Position Properties window. Write below the position of the point and compare it with the published coordinates based on the NAD 1983 datum:

Latitude: _____ Longitude: _____
Altitude: _____
Latitude: 38* 02' 20.57581" Longitude: −84* 30' 18.67673"
Altitude: 974.5 feet
Differences : _____ _____ _____

{__} A second of latitude is about 30.75 meters. A second of longitude (at this latitude of 38 degrees) is about 24.36 meters (i.e., 30.75 times the cosine of 38 degrees). What are the differences for northing, easting, and altitude in terms of meters? A meter is equivalent to 39.37 inches, based on U.S. survey feet.

Differences (meters): _____ _____ _____

The approximate answers are 3.8, 5.5, and 11.4 meters.

{__} To verify that I have given you the correct coordinates for the McVey monument, look it up on the Internet. The McVey monument's designation is HZ0339. The web site is: www.ngs.noaa.gov. Locate the place on the web page that allows you to "Find a point."

To review: You just learned how to differentially correct an SSF file. What you did is called postmission processing, or postprocessing, because considerable time elapsed from the time the file was recorded in the GPS receiver and the time it was corrected by you. As mentioned previously, another way to improve GPS data is called "real-time differential correction," whereby the base station transmits a radio signal that is received by the rover (s), allowing them to correct their data almost instantly. This allows the roving receivers to display the more nearly correct position fixes immediately. One might use such a capability to bring a ship into a harbor. The objective is to miss the rocks at that moment; postprocessing would hardly be appropriate. We will spend more time discussing the real-time differential correction method in Chapter 7. But for using GPS data in a GIS, **postmission differential correction is the way to go**.

PROJECT 4C—McVey Waypoint

Waypoints—Using One to Check Your Work

{__} The McVey monument is a good candidate for a waypoint since it is a known reference point. We will do this in order to see another way of calculating the distance from a corrected average point to a known point. Still in the __:\GPS2GIS\McVey_NGS directory you will find a file named V062318C.SSF generated at the McVey monument in June of 2000. (Click on the folder icon on the Project toolbar.) This is a file taken after SA was discontinued in May of 2000. Also, if you navigate to the "Base" directory, you will find L0062318.SSF. Close the folder.

{__} Correct V062318C.SSF with L0062318.SSF.

{__} Make V062318C.SSF produce a Generic_point file named V062318C_PNT.SSF.[11]

{__} Make V062318C.COR produce a Generic_point file named V062318C_PNT.COR.

{__} Make V062318C.COR produce a Generic_line file named V062318C LINE.COR.

{__} Display the two point files and the one line file. With the pointer cursor select each of the point file symbols. Note which name goes with which. We could again compare the results of this operation with the published coordinates by the pencil and paper method of Project 4B, but let's look at a more elegant and efficient way. We will establish a waypoint to represent the McVey marker and display the waypoint at the same time as the three files above

Make a Waypoint in Pathfinder Office

{__} Make certain the Options are set right for defining the waypoint: Latitude and Longitude, NAD 1983 (Conus), Altitude Measured from MSL, Altitude Units and Distance Units: U.S. Survey Feet, Style: DD*MM'SS.SS.

{__} Under File click Way points, then New. In the New Waypoint File window, navigate to the __:\GPS2GIS\McVey_NGS folder. This window will allow you to make a file of as many waypoints as you want. The set of waypoints will appear and disappear from the screen together. In our case we will make only one file containing one waypoint. The window will suggest that you call the new waypoint file something like w<date>a.wpt but change it to McVey_yis.wpt.[12]

{__} Okay the New Waypoint File window and another window will appear named Waypoint Properties. Punch Create and a third window, Create Waypoint, will be displayed.

{__} Make the waypoint name McVey. Type in the latitude, longitude, and altitude as shown by the alphanumeric strings below:

38*02'20.57581"
–84*30'18.67673"
974.5

The Create Waypoint window should now look like Figure 4–12.

{__} Press Save, and then Close in the Create Waypoint window. The Waypoint Properties window will reappear. In your file McVey.wpt you have only one waypoint: McVey. Check that the

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[11] Shortcut hint: If in the Output File window you click on a file name, that name will replace "grouped.xxx," saving you typing.

Figure 4–12. Creating the McVey Waypoint.

coordinates of McVey are correct. If not, Edit them. When done, close the Waypoints Properties window.

{__} If it is not displayed, open the waypoint file: File ~ Waypoints ~ Open ~ McVey_yis.

{__} Select a blue triangle to represent the waypoint under View ~ Layers ~ Waypoints ~ Symbol. Make the Map window active. The newly created waypoint may appear in the Map window. If it doesn't, click on the Zoom Extents icon (magnifying glass with the equal sign [=] in it).

{__} Set the distance units to meters.

{__} Measure the horizontal distance from the COR point to the waypoint. _____. To the SSF point. _____

{__} With Data ~ Measure, determine the approximate north-south distances from the datapoint to the waypoint. COR:_____SSF: _____

{__} Do the same for the east-west distance. COR: SSF: _____

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12 Where "yis" indicates your initials—you know the drill.

{__} Can you find the difference in altitude? COR: _____
SSF: _____

PROJECT 4D—Vancouver

Look at Some Corrected Line Data

Next we want to look at a set of some line files that have been postprocessed. The primary difference between these files and the previous ones is that these fixes represent a track from a moving antenna, rather than an approximation of a single specific point. Obviously, the overall accuracy of the corrected file will be less, because it would not be appropriate to average the fixes in the file. You will, however, notice a dramatic improvement in the quality of the data collected by a "roving" receiver—whether it is carried by automobile or on foot.

The files you are going to look at first were taken in January of 1994 by both automobile and hiking in the area of Whytecliff Park near Horseshoe Bay, in West Vancouver, British Columbia, Canada. A road map of Vancouver would be useful (are you an AAA or CAA member?) but not necessary. Or you could look up the area on one of the map web sites, such as www.mapquest.com.

{__} Make a Project named Whyte_yis. Use __:\GPS2GIS \WHYTE as the primary directory.

{__} Set the Coordinate System to Latitude Longitude displaying in decimal degrees. Set the Datum to WGS 1984. Measure the altitude from MSL (EGM96 [Global]) in meters. Set Distance Units to meters. Make the North Reference Magnetic. Set the Time Zone to Pacific Standard.

{__} The first file you will view is along the Trans Canadian Highway (the Canadian "Interstate") traveling west from its intersection with 1st Avenue in Vancouver to Horseshoe Bay in West Vancouver. Display the file ROAD1_OLD.SSF; it is a Not In Feature file. Zoom to Extents.

{__} Whoops! Something strange may have happened? You might have a little dot at the west side of the screen and a blue triangle in the east. The almost five million meter distance across the top of the map gives a clue. Close the waypoints file left over from the previous exercise: File ~ Waypoints ~ Close. Zoom extents again.

{__} Open whatever windows you need to answer the following questions. How long was the trip in minutes? ____ In kilometers

(which are standard in Canada) as the crow flies? _____ Along the road? _____. By using a vertical line with the measure command, estimate the difference between True North and Magnetic North in southwestern Canada. _____ °.

{__} Minimize the Pathfinder Office window (by clicking on the little bar icon near the upper right corner). Close any other windows you need to in order to get to the Desktop. Using the Windows Explorer or "My Computer," bring up a window containing a list of files in the __:\GPS2GIS\WHYTE\BASE folder. Notice a file named "W4012921 .EXE." The name of this file has the format of a community base station file, but the extension is EXE, not SSF.

W4012921.EXE is an interesting type of file. An EXE file is usually a computer program—one that may be executed by the *Central ProcessingUnit* (CPU) of your computer. This particular file is partly program, but mostly compressed data. It could be called a "self-extracting GPS data file" because when it is executed it generates a community base station SSF file.

{__} Execute "W4012921.EXE." You do that just by pouncing on the icon next to its name. A DOS window will appear momentarily while the new SSF file is extracted.

{__} Again examine the files in the directory. You will notice that "W4012921.SSF" has been added. This is a standard storage format file from the Whiterock, British Columbia, (B.C.) community base station, located near the U.S. border in southwestern British Columbia, about 53 kilometers (33 miles) from Horseshoe Bay.

{__} Revive Pathfinder Office by clicking its button on the task bar. Open the file ROAD2_OLD.SSF. What happened here, though you can barely tell it from the GPS track, is that the car proceeded from the southeast (on Marine Drive), went mostly west, then northeast, until the road made a large "U," headed southwest and then into the parking lot of Whytecliff Park at the far left of the track image. It cruised around the lot, and returned, going northeast, along the road it had just taken. Finally it turned left and encountered a dead-end, where it parked.

{__} Now open the same file but add the file ROAD2_OLD.COR, which is a file that was made by differentially correcting ROAD_OLD.SSF. The base file that was used was W4012921.SSF (which, as you may recall, you generated by executing the file W4012921.EXE). ROAD2_ OLD.COR was turned into a Line_generic file so that you could distinguish it from its

uncorrected cousin. Use View ~ Layers ~ Features if necessary to display these two files differently.

Now, if you reread the description of the car's track in the previous step, the path should be more obvious. If you want to look at a map of the area you can go to www.mapquest.com and put in the address 6992 Hycroft Road, West Vancouver, B.C., Canada. The red star shows where the car parked.[13]

The receiver was then carried by hikers through the park, from the dead-end in the northeast to the parking lot in the southwest. Two files represent this trip: HIKE1_OLD.SSF goes from the dead-end, where the car stopped at the end of the ROAD2_OLD.SSF file, up to the pinnacle in the park. A photo of the view from the pinnacle can be seen by opening The_Ferry.jpg, which can probably be done by pouncing on the file name or with your Internet browser. HIKE2_OLD.SSF goes from the pinnacle down to the Whytecliff Park parking lot in the west.

{__} Display HIKE1_OLD.SSF.

The jagged track does not represent where the hikers actually walked. The spikes in the track probably come from a combination of selective availability and frequent changes in the "best PDOP" constellation, caused by terrain interference. Contributing further to the poor quality of the track was the fact that the receiver was set to record a point each time the receiver calculated that it was 20 meters from the last point, rather than every so many seconds. This has the effect of recording any spurious distant point that is generated. Recall that the receiver calculates a fix about every two-thirds of a second; whether or not that fix is recorded in the memory depends on how you have the rover parameters set. If the criteria for recording a fix is how far that fix is distant from the last fix observed, then you can see that fixes that are distant because of errors will be recorded. If the rover is set to record a fix periodically instead, the chance that an errant fix will be recorded is reduced.

{__} Continue to trace the hike through the park by adding HIKE2_OLD.SSF to the set of open files. Here the GPS receiver was set to record points every 10 seconds. The track looks significantly better.

Differential correction makes a huge difference, as you will see:

{__} Display the corrected files HIKE1_OLD.COR and HIKE2_OLD .COR together. These tracks aren't perfect—note some jags and double-backs—but at least you get a reasonably cohesive picture of the trail. As it turns out, not all the fixes in the

rover file were corrected, which probably accounts for the spurious points remaining. Finally, display these together with ROAD2_OLD.COR. The corrected GPS tracks shown here are certainly not perfect, or even very nice. But you can hardly deny that differential correction made an enormous difference in the quality.

In May 2000, the hikers repeated the trip to Horseshoe Bay. They used better equipment and, more importantly, selective availability was turned off.

{__} Set the time zone to Pacific Daylight Savings. Repeat the displays indicated above but use the SSF and COR files of ROAD2_NEW, HIKE1_NEW, and HIKE2_NEW. Perhaps display the SSF files in the background and the COR files in the standard way. You will have to zoom up pretty far to see the differences in the tracks. (By the way, the car took a little side trip just before the parking area—different from the 1994 data.)

Just off the southwest beach of Whytecliff Park is a bit of rock that is a peninsula at low tide and island at high tide. A photo image of the location is in The_Rock.jpg. The hikers climbed this and acquired the file V052223E.SSF, which was corrected later to form V052223E.COR.

{__} Group each of these files to form V052223E_1PT.SSF and V052223E_1PT.COR and display them. Measure how far apart these points are from each other. _____. Write the coordinates of the corrected point in decimal degrees. Latitude: _____. Longitude (don't forget the negative sign): _____. (You will need these coordinates for the next step.)

{__} Using an Internet browser, bring up www.mapquest.com.[14] Display the largest possible map at the most detailed level, using the coordinates you wrote above. The red star should show up on the island. If you zoom out to a slightly smaller scale you should be able to see Hycroft Road where the car was parked and infer the location of the hiking trail through the park.

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[13] At the time of this writing, mapquest.com was having trouble finding West Vancouver. You might have to put in the geographic coordinates: 49.3766 & −123.2837. Another technique that worked was to ask mapquest to lay out a trip from 6994 Hycroft to 6992 Hycroft in West Vancouver.

[14] "www," as has been noted by others, sometimes stands for "worldwide wait." You may need to be patient.

PROJECT 4E

Differentially Correct Some Supplied Line
Data—New Circle Road Again

In this exercise you will differentially correct two files generated by a car going around a portion of New Circle Road and returning, in September of 1999 (9/99). Most of the trip took place using the four-lane divided highway. You will also look at a DOQ of part of that highway and see the GPS tracks overlaid on it. We assume that Pathfinder Office is running as you begin to follow the steps below.

{__} ***Make a Project:*** Under Files select Projects. When asked to select a project, click New. Give the new project the name CircleRd_999_yis. The directory structure has already been prepared for you with base, export, and backup folders. Simply specify C:\GPS2GIS\CircleRd_999 as the primary directory. When you are done creating the project, the Current Project identifier on the Project Toolbar should read CircleRd_999_yis (or as much of it as the text window lets you see).

{__} To get an idea of where the New Circle Road is with respect to the University and Lexington, display the waypoint McVey by opening the waypoint file McVey_NGS_yis. Zoom to extents. (If you didn't close the Whytecliff Park files you may get a rather large distance reported for the width of the window. Fix that by closing both the normally displayed files and the background files.)

{__} Use the "Open Folder" icon (the leftmost one on the Pathfinder Office **Project** Toolbar) to look at the folder for the project, CircleRd_999_yis. In this folder you will find two rover files: S090519A.SSF and S090519B.SSF. These are the files you will correct. Resize the window so it doesn't take up much room.

{__} ***Examine the files:*** Use the "Open" icon (the leftmost one on the **Standard** Toolbar) to open the files S090519A.SSF and S090519B .SSF. Make "Not In Feature" data represented by the thinnest red line. Then use View ~ Map to look at both of these uncorrected SSF files (use Ctrl-click to select both). You will notice an area at the north end of the trace where the two tracks run along together along an arc. If you zoom up on that area you will be able to see that the tracks merge and cross at various points— an indication that the GPS points contained considerable error. Return the window to the full extent of the GPS tracks.

{__} Using the __:\GPS2GIS\CircleRd_999 window[15] that you opened previously, pounce on the icon of the Base folder of CircleRd_999. There you should find an EXE file: U9090519.EXE. When executed, this will make the base file that you will use to correct the rover files. Pounce on the EXE file icon to execute it. An SSF file of the same name should appear in the folder. (If there is already SSF file of a given name in the directory you will be asked if you want to overwrite it. You do; type a "Y.") Once the SSF base file is present, close the folder.

{__} Start the differential correction process from either the Utilities menu or the Utilities toolbar. You will correct the two rover files with the base file, both at the same time. Under Rover Files click Browse. Select the rover files by clicking on one of them with the mouse cursor, then hold down the Ctrl key and click on the other one. Click Open.

{__} *Select the proper base file to correct the rover files:* Under Base Files click the Local Search button. Pathfinder Office will then automatically select the folder __:\GPS2GIS \CircleRd_999\Base. Punch Search. Examine the Confirm Selected Base Files window, then okay that window. Agree to the given Reference Position of the Base Station.

{__} Under Corrected Files the Output Folder should be __: \GPS2GIS\ CircleRd_999 and the file extension should be COR. Under Processing make sure that Code Processing will be done. Press OK in the Differential Correction window. The differential correction process should proceed, leaving you with S090519A.COR and S090519B .COR in the project directory.

{__} Open the project file folder (from the Project Toolbar) to see that everything is there. Pounce on one of the AUR files. Make it full screen. It will tell you more than you will want to know about the differential correction process. Dismiss the window.

You will recall from Chapter 3 that a digital orthophoto image is an aerial photograph that has been calibrated so that it may be used as a map. Here again we make use of this capability.

{__} *Prepare the map of the GPS track so that a digital orthophotowill be properly positioned:* The configuration you want is the U.S. State Plane 1983 coordinate system, Kentucky North Zone (1601). The datum is NAD83 (Conus). The coordinate

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[15] The folder may have disappeared but it can be redisplayed by clicking its button on the task bar.

units, altitude units, and distance units are Survey Feet. The Time Zone is Eastern Daylight. Using the Units, Time Zone, and Coordinate System choices under the Options menu, set up these parameters.

{__} ***Bring up a digital orthophoto image as a background to thefiles you have selected:*** From the File menu select Background. In the Load Background Files window "Remove" any existing file names, then click Add. The window that appears (Add Background Files) might represent the folder __:\GPS2GIS \CircleRd_999. (If it doesn't, navigate to that folder.) Select the file j41se9.tif and click on Open. Read and okay a reminder if it shows up. Back in the Load Background Files window review the System, Zone, and Datum specifications. It probably appears that all is well, but it may not be. Click on "Change" and correct any parameters so they match the ones given in the previous step. Be particularly careful regarding Coordinate Units. In Kentucky they are in Survey Feet! Okay the Coordinate System window. Okay the Load Background Files window. Zoom to extents. A small image should appear in the Map window.

{__} Make the Pathfinder Office window occupy the full screen. Maximize the Map window. Look at the GPS tracks that represent a round trip on a divided highway. Using Zoom In, enlarge the orthophoto image. Notice how the GPS tracks across it follow the divided limited access highway (sort of). However, they appear to be well outside the lanes of the highway.

{__} Instead of the SSF files that you have displayed, open the COR files. (The Map will go back to full extent, so you will have to zoom in again.) You should see a dramatic improvement: The tracks remain separated for their entire distance (except at the beginning and end where sharp turns and two-lane roads were involved.) If you zoom up on the orthophoto you will see a dramatic improvement. It appears that the car actually stayed on the pavement for the most part.[16]

Differential Correction Also ImprovesGPS Accuracy with SA Off

Now we will revisit the Chapter 3 Project in which we looked at the effect of turning SA off as a car was traveling around New

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[16] At the south end the lines leave the road. The error might be in the photo.

Circle Road. You will correct the SSF file taken then and see even further improvement, shown by the DOQ we used in Chapter 3.

{__} Change the Project to ByeByeSA.

{__} Differentially correct the file NoSA_Moving.SSF, using L0050204. SSF—a base station file covering the hour of transition.

{__} Arrange the layers so that a moderate-thickness red line represents Not in Feature data.

{__} Display NoSA_Moving.SSF.

{__} ***Prepare the map of the GPS track so that the digital orthophotowill be properly positioned:*** Use the U.S. State Plane 1983 coordinate system, Kentucky North Zone (1601). The datum is NAD83 (Conus). The altitude units, coordinate units, and distance units are Survey Feet. The Time Zone is Eastern Daylight.

{__} ***Bring up the digital orthophoto image as a background to thefiles you have selected:*** Add the file __: \GPS2GIS_ByeByeSA\no_ sa_ncr_doq.tif to the set of background files to be displayed. Make the main Pathfinder Office window occupy the full screen. Maximize the Map window. Zoom to Extents. Zoom up on the part of the red track that crosses the DOQ. Look at the GPS tracks that represent the part of the trip on the divided highway that took place during the transition from "SA on" to "SA off."

{__} Now add NoSA_Moving.COR. (You can easily add files to those already displayed. In the Open Window the currently opened file names are shown overlaid with a gray tint. If you want to keep those files, hold down Ctrl while you select the new files with the mouse.)

Notice three things.

1. That differential correction greatly improved the GPS track while SA was still on,
2. That differential correction improved the GPS track after SA was turned off. Now the track is not only in the highway right of way, but in the correct lane as well. And, just FYI,
3. When you open two files together Pathfinder Office connects the last fix of the first with the first fix of the second— which explains that red line that cuts cross country.

{__} Zoom up more so you can get to see the actual lanes of the highway toward the eastern side. Look at the corrected trace. It appears that the car making the GPS track sideswiped other cars

on the highway. (Fortunately, those cars had been there many months before so there was no problem.)

PROJECT 4F—The OK Campus

More GPS Files and DOQs

In this Project we verify again that differential correction has great value—here we superimpose a GPS trace, on a digital orthophoto, made by walking.

{__} Make a Pathfinder Office project named UK_Campus_yis. Specify its directory to be __:\GPS2GIS\UK_Campus_yis.

{__} *Use the operating system to copy the contents of* __: \GPS2GIS\UK_Campus

to

__:\GPS2GIS\UK_Campus_yis

by doing the following:

Minimize the entire Pathfinder Office window. Open two windows showing the contents of both folders UK_Campus and UK_Campus_yis. The latter should be empty except for folders labeled "backup," "base," and "export." Click in the title bar of (UK_Campus. Hold Ctrl and press the "A" key to select all folders and files. Hold down the CTRL key and press the "C" key to copy the highlighted files and directories onto the operating system clipboard. Click the title bar of (UK_Campus_yis, hold down Ctrl, and press the "V" key to paste the contents of the clipboard into that folder. Say Yes to any complaints that folders already exist.

The directory __:\GPS2GIS\UK_Campus_yis should now contain at least the following:

- the rover file r020919b.ssf
- the doqqqq image file J41se8w.tif and its world file J41se8w.tfw
- a directory "base" that contains U0020919.exe and L0020919.ssf
- two empty directories, "export"[17] and "backup"

The file r020919b.ssf was made by a student carrying a GeoExplorer on the University of Kentucky campus, from a point almost on South Lime-stone Street, along a sidewalk that traverses the front lawn (which contains the McVey monument), past the Administration building, across the southwest border of the plaza in front of the main faculty office building, along a

sidewalk between two major library buildings (which blocked the signal in that area), and past the president's home. He turned right on Rose Street, traveling southwest until coming to a main UK entrance where he turned right again into a parking area. Another right turn led him to intersect his earlier path. (If you are interested in an Internet map of the place, the coordinates are those of the McVey monument: 38*02'20.57581"N and 84*30'18. 67673"W.)

The files j41se8w.tif & j41se8w.tfw constitute a digital orthophoto of a portion of the UK campus.

The files in the directory "base" (U0020919.exe and L0020919.ssf) are files downloaded from two Trimble Community Base Stations in Lexington. Either of them could be used to adjust the points in r020919b.ssf to make r020919b.cor.

{__} *Fix up the parameters:* In Pathfinder Office, under Options, make the Distance units U.S. Survey Feet. For Coordinate System, pick U.S. State Plane 1983. The Zone should be Kentucky North 1601. Coordinate Units should be U.S. Survey Feet; the Altitude Units should be Survey Feet as well. Make the Time Zone Eastern Std USA.

{__} Open and display the waypoint file McVey_yis.wpt file. (You may have to browse for it. It's in __:\GPS2GIS\McVey_NGS. You may also have to zoom to the full extent of the open feature and background files. Close any other than the waypoint.)

{__} Display the file j41se8w.tif in the background (after removing any other files in the Load Background Files window).

{__} Bring up the Map and make it full screen. Open the Position Properties window. The Map Window may shrink. Resize the Map window and move the Position Properties window off to the side so that both windows are visible and not overlapping. Zoom to Extents. Open and display the rover file r020919b.ssf.

{__} Make the Not In Feature layer be displayed with heavy red dots; the dots should not be joined.

{__} Zoom up on the beginning of GPS track. It is pretty hard to see what the path was. Using the Position Properties window, look at the location of the First fix. Click the DOPs tab. Move several positions along the track using the > button. Note that when the path takes a sudden jump a different set of four "Satellites" is used

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[17] We'll use the export directory in Chapter 6 when we make an Arc View shapefile from the data in r020919b.cor.

to compute the position. This shows that the error produced by one set of satellites may be quite different from the error produced by another set.

{__} Note the position of the McVey monument relative to the GPS track.

Correct the Rover File

{__} Click on the button on the Start bar that will bring up the window of __:\GPS2GIS\UK_Campus_yis. (Alternatively you could click on the project folder on the Project Toolbar.) Pounce on the "base" folder to bring up the list of files in __:\GPS2GIS \UK_Campus_yis\base. Pounce on U0020919.exe to have the computer execute it. You should shortly see the appearance of U0020919.ssf. The self-extracting (.exe) base file just created an .ssf file. Bring back Pathfinder Office if you minimized it.

{__} ***Differentially correct r020919b.ssf using U0020919.ssf:*** Since you have two base station files, you can ask Pathfinder Office to choose one of them based on the Preferred Base File Prefix. Choose U. Then when you get the screen showing the Reference Position of the base station, write down the Latitude, Longitude, and Altitude here:

Lat: _____ Lon: _____ Alt: _____

Complete the process, making sure the resulting COR file goes into __:\GPS2GIS\UK_Campus_yis.

{__} Display r020919b.cor. It should look a lot more reasonable. Compare the path with the description of the GPS track given above. Use zoom and pan (including the Auto-pan to Selection feature if you want to move along the path using the Position Properties window) to look at how closely the track follows the sidewalks.

(This is a good place to notice a characteristic of orthophotographs. Early in the walk, as the GPS track crosses a plaza, you will notice a tall building to the northeast of the track. Zoom up on that building. You can see the southwest side of the building clearly. You may assume that, in reality, the top of the building is precisely over the base, though on the photo the top of this 18-story building appears to be displaced by some 80 feet horizontally. (Use Measure.) The lesson here is that **digital orthophotos depict locations accurately only at ground level**.)

{__} Use the operating system to copy (Ctrl-C) U0020919.SSF that is in __:\GPS2GIS\UK_Campus_yis\base and paste (Ctrl-V) it into __:\GPS2GIS\UK_Campus_yis.

{__} Open U0020919.SSF (in the Base folder of__:\GPS2GIS \UK_ Campus_yis) as a Background file. Even though it is a base station file it may be displayed (and differentially corrected as you will see shortly). Zoom to the full extent of all open and background files. Under View ~ Layers ~ Background display Not in Feature files with a thinness pink line. The building over which the fixes cluster is the Forestry Building, where the OK Community Base Station is located. Zoom in so that you can see this building and those surrounding it. Measure the span of the fixes in this file: _____ This will give you a good idea of the best accuracy that could be expected when selective availability was active.

Correct a Base Station File

{__} ***Start the process of differentially correcting U0020919.ssf withL0020919.ssf (both in the "base" folder) to produce U0020919.corin the __:\GPS2GIS\UK_Campus_yis folder:*** In the Differential Correction window choose Settings to make certain that only corrected positions are placed in the output file. (Make sure that you specify the preferred base station file letter to be "L," not "U"; correcting a base station file with itself would be sort of cheating.) When finished with the differential correction process, display this file. Note that the points all fall within a circle of diameter of less than a foot, except for one outlier that pushes the span to about 1.3 feet. You will have to zoom out considerably to see the context of the fixes.

This exercise gives you an idea of how well differential correction can work. Basically, for using GPS for GIS, where accuracy is all-important, differential correction is vital. It is therefore relatively unimportant that selective availability was removed. It is hard to imagine a situation in which you would not differentially correct GPS files that are going to be used to build a spatial database.

{__} Use the grouping utility to make the file U0020919_pt.cor.

{__} In the __:\GPS2GIS\UK_Campus_yis folder you will find a waypoint file named UK_Community_base_Station.wpt. It consists of a waypoint named Calvin. Open that file and display the waypoint.

{__} Repeat the process of correcting a base station file, but this time correct a file that was taken after selective availability was eliminated. Correct U0050219.SSF with L0050219.SSF.

{__} Change settings: Lat-Lon, WGS 1984, ddmmssss, meters all around, and HAE. By the way, changing the projection will force Pathfinder Office to unload the DOQ, since image files cannot be projected and maintain their integrity.

{__} Use the record editor to derive statistics for the file U0020919. Compare the results with the location of the base station that you wrote down earlier.

Surveyed: Lat: _____ Lon: _____ Alt: _____
Calculated: Lat: _____ Lon: _____ Alt: _____
Differences:_____ _____ _____

{__} Move to the parent directory: __:\GPS2GIS \UK_Campus_yis. Delete the .tif file.

When one does a set of scientific experiments to determine the truth about "something" one usually wants to hold fixed ("constant") most of the things that could affect the outcome of the experiments while varying one or two other things. For example, if you were trying to determine a law for how long it took an object dropped from a height to hit the ground you might want to drop the object from different heights and record the duration of the fall. But you would always want to use the same object—not a billiard ball one time and a Ping-Pong ball the next. One of the problems in determining accuracies of GPS measurements is that it is impossible to repeat experiments under exactly the same conditions. Everything changes. The satellites move. The atmosphere changes composition. And so on. So absolute statements about GPS accuracy are hard to make honestly. One approach to determining GPS accuracy is to make lots of different measurements at different times and attempt to "get an idea" of "what you might expect." Not completely satisfying, but it's the best we can do.

What follows is a miniexperiment, easily done, that will give you an idea of the best you could expect from differential correction. We take five base station files and correct them (with another base station) and look at how much improvement was made. Base station files are good SSF files to work with since (a) we know exactly where the antennas are, (b) they collect a lot of data (every three or five seconds), and (c) their antennas are mounted so that they get really good reception.

{__} Make a project that points to the folder __:\GPS2GIS \Compare_ ssf_cor. There you will find SSF files U0070707, U0080808, U0090910,[18] U0101010, and U0111111. These are files generated since selective availability went off. They are about a month apart so they used different constellations. While the file names have a certain pattern to them the files themselves probably constitute a fairly random sample of DOPs and signal strengths. In the "base" folder are base station files that will correct most of the points of the SSF files.

{__} *Differentially correct the five flies.* You can do all five files at once. Start the differential correction process. Select the first SSF file by clicking on its name, then select the remaining four SSF files by holding down Ctrl and clicking. Ignore complaints that the files are not rover files. Conduct a Local Search for the base files (preferred base station prefix "L") and you will see all five files set up to be corrected at once. Approve everything and wait —there are lots of points for the computer to calculate.

{__} *Group each of the SSF files into five point features:* You can again process all five files at the same time. Put the results into GROUPED.SSF.

{__} Open GROUPED.SSF. Represent the waypoint Calvin with a blue triangle. Represent a Point_generic feature as a red square. You may have to Zoom to Extents to get the waypoint included on the map. Measure some distances. This gives you a good idea of the best horizontal accuracy you can expect from uncorrected data.

{__} Open the position properties window. Click on the waypoint and note its altitude (HAE). _____. Now click on the other points and note their altitudes. (You can tell which is which by the date.) You now have an idea of the best vertical accuracy you can get from uncorrected data.

{__} Group each of the COR files into GROUPED.COR. Display and measure these. Note their altitudes.

{__} Now open and display both GROUPED.SSF and GROUPED.COR together. You should now have a pretty good idea of how much differential correction can improve excellent SSF files. In general, your SSF files will not be as good—so take that into consideration.

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[18] I wanted to use U090909, for the sake of maintaining the pattern, but the equivalent base station file wasn't available. That happens sometimes. For critical work you probably should investigate ahead of time the reliability of any base station you intend to use.

Look at a High Resolution Color DOQ

Sometimes, as you've seen, DOQs are in black, white, and grayscale. In this project you will see the results of part of the walk across the University of Kentucky campus overlaid on a high-resolution color orthophoto. The grayscale orthophotos you used previously have cells a little more than three feet on a side. The color orthophoto that you will load next uses 6 inch cells.

(Unless you have a computer with a fairly sizable memory and a good bit of free disk space, you may not be able to do this part of the project. The size of the grayscale orthophotos is somewhat over two megabytes. The color orthophoto covers somewhat less territory but has resolution about six times higher (which means about 36 times as many cells in a given area, and—because it is in color—requires many more bits per cell. Therefore, it will not surprise you that the color orthophoto is larger in terms of memory size. It may surprise you that it is about 50 times larger—102 megabytes compared to about 2.2 megabytes.)

{__} Change settings: U.S. Survey Feet everywhere. U.S. State Plane 1983. Kentucky North 1601. Eastern Standard.

You may proceed in either of the two ways, depending on the speed of your CD-ROM drive and disk space available. One is to load the large color orthophotos into PathFinder Office directly from the CD-ROM; the other is to copy the data onto the hard drive and load the images from there. If you choose the latter:

{__} Make a folder in __:\GPS2GIS named Temp_Color_DOQ. With the operating system, copy the files NorthEast.tfw and NorthEast.tif from the CD-ROM folder UK_Color_Orthos into Temp_Color_DOQ.

{__} Examine the color orthophoto __:\GPS2GIS\NorthEast.tif together with U0020919.SSF. Zoom up on the area where the GPS track crosses the image and the office tower appears to its northeast. Notice the shadow cast by the building. Notice how crisp everything appears compared to the grayscale orthophotos. This happens partly because of color, but mostly because the area covered by each cell of the grayscale orthophoto is now represented by more than 36 cells. If you zoom out you can easily pick out individual cars and trucks. The little dots making shadows on the sidewalks are people.

{__} Delete the folder Temp_Color_DOQ.

PROJECT 4G—DOP Matters

You must not assume that Differential Correction will take out all errors, or even all significant errors. In particular, multipath errors and errors caused by high PDOP can remain after the correction procedure has been applied. The file H092702B.SSF is an 11-hour file taken by a GeoExplorer receiver with the PDOP mask set to 99. File H092720B.COR is a file made by correcting four hours of the data of file H092720B.SSF.

{__} In the folder __:\GPS2GIS\High_PDOP open the file H092720B .SSF. Display it, joining its points with a thin black line. Note that, even though selective availability was not active, some points are very wide of the mark—as much as 200 meters.

{__} Check on the DOP values to the most far-ranging points at the ends of spikes. Some have very high PDOP values. Others, probably the result of multipath error, have reasonable PDOPs.

{__} Open file H092720B.COR as a background file (it's in the same folder). Set up View ~ Layers ~ Background so that Not in Feature files display as a thin red line. Note that the spikes are still there. In a couple of cases in appears that differential correction made things worse.

The moral of the story is that differential correction cannot compensate for errors caused by high PDOP or multipath.

PROJECT 4H—Your Data II

Correct Your Own Data

In this project you will correct the data you took in Projects 2A (fixed point) and 2B (a trace made by moving the antenna). Or you might choose to correct some other data. You will learn how to find and download data from a base station.

{__} Return to the Project __:\GPS2GIS\Data_yis. Examine the data you collected in Projects 2A and 2B. What are the last seven characters of the names of the base station files? You would need to differentially correct these files?[19] Recall that the format of a base station file is XYMMDDHH.SSF.

X_____

X_____

It may take a little research to determine if there is a base station within 300 miles of your location but GPS equipment vendors can usually supply the information. When you find one,

fill out the form at the end of this part. If it's a Trimble compatible station you want what the company calls Community Base Stations. One way to find one is to point your web browser at:[20]

www.trimble.com/trs/trslist.htm

or

www.trimble.com/gis/cbs/

and you can select base stations by state, province, region, and/or city. Information on how to retrieve the base station computer file can be found here also.

{__} Bring up a browser and check out the URLs above. Explore your geographic region. It may be obvious what base station is closest to you and how to download it. In any event, let's look at a different method before we do any downloading. Keep your computer connected to the Internet.

A more elegant way to locate a nearby base station is provided directly by the Pathfinder Office software and a Trimble Navigation web site. Once you open an SSF file that you want corrected, you can direct the software to automatically download a list of base stations to your computer, sorted in the order of distance from the positions in your SSF file. Assuming you have the correct permissions from the base station owner, the software can even download the base station file and automatically produce the COR file.

{__} Start the differential correction utility. Select one of your data files as the Rover File. Under Base Files, click "Internet Search." In the window that comes up, click New. In the New Provider window choose "Copy the most up-to-date etc." option. What happens now may depend on how you are connected to the Internet, but what can happen is that your computer will download a list of many dozens of base stations. (Please see Figure 4–13.) The ones closest to your SSF file's location are listed first and, if you are on the North American continent, those in South Africa, Australia, and New Zealand listed last. If you pick a base station and choose Properties you have the option of going to

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[19] Actually you might need more than two base station files. If your data collection extended over parts of two consecutive hours you need the base station files that cover the second hour as well.

[20] These worked at the time of this writing and appeared identical. But web pages have a nasty habit of changing so if these web pages do not appear go to www.trimble.com and navigate to, or search for, the "Community Base Stations" list or the "Trimble Reference Station List."
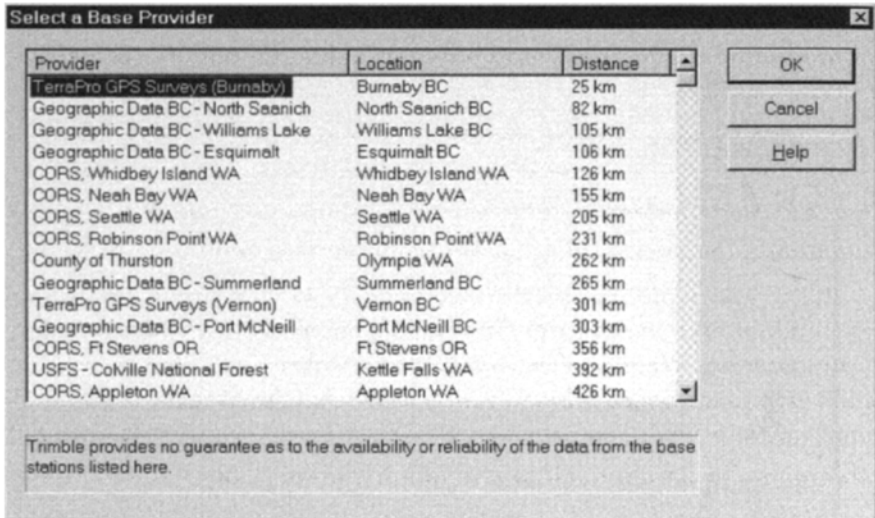
Figure 4–13. List of Base Stations from the Internet.

their web page directly or sending them E-mail. If you OK this window you may have the option of downloading the files you need directly. Or you may not, since there may be impediments—both technical and/or commercial.[21]

{__} Using the information above, plus instructions from your teacher or employer, obtain the appropriate base station files. Such files are usually kept on hand at the base station locations for at least several months after they have been collected. As I've described, you may well be able to download these files from the web, or through the download capability of your browser through a process called "anonymous FTP" (File Transfer Protocol). Bring the files into the Base folder of the Project you set up for the data in 2A and 2B. If the files are EXE files, or "zipped" files, convert them into SSF files.

{__} Use the differential correction process on the files you collected. Display the SSF and COR files with Pathfinder Office software.

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[21] Some stations charge for their services and differential correction files.

Exercises

Exercise 4–1: From reading and doing the projects in this chapter you have probably formed some ideas of the accuracies (both horizontal and vertical) you might expect from an autonomous GPS receiver. Make a table that puts these numbers together. Add to your table the accuracies you might expect once you differentially correct the data.

Exercise 4–2: In \GPS2GIS\ROOFTOP you will find two files, C120600G .SSF and C120600G.COR, which represent another attempt to find the location of the coordinates of the rooftop of PROJECT 4A.

{__} Enter the GPS software and set the Project to "Rooftop." Set up UTM coordinates in meters. Set the height as "Geoid," meaning height above mean sea level (MSL) and the altitude units as meters. Set the Datum to WGS84.

{__} Display these files so you can tell which is which (use the Grouping utility or the Background capability). Both plots look really terrible, with large dispersions. Use the Measure tool; you will determine distances between some points of more than half a kilometer. Furthermore, the "corrected" file shows not one, but several clusters of points. What's going on here?

{__} Use Position Properties to examine some points in each file. Particularly suspicious are the "Altitude" numbers. The altitudes all seem to be about 47.5 meters *below* sea level. Since the antenna was at a geographic point almost 300 meters above sea level, we may suspect that some altitude setting is the culprit. We are also suspicious because the altitudes seem not to vary from point to point. Now notice that Position Properties reports that these points, whether corrected or unconnected, are 2-D rather than 3-D.

So there is the answer. Some doofus (the author, actually) had the GPS receiver set on 2-D or Auto 2D/3D while collecting this particular file. ***Youcan only use those settings if you manually and correctly enter the altitude***—obviously not something that happened here, since the receiver thought the altitude was –47.5 meters MSL.

The moral of this story is an old one, related to using a computer to turn data into information. It is known as GIGO: "Garbage In, Garbage Out."

Exercise 4–3: When you use GPS to collect line data you have to be aware that each fix on the line is a single reading, with the error implications that that has. In other words, there is no

possibility of averaging. Something else to be aware of is that natural and human-made objects frequently are curvy and that a GPS linear track is composed of a sequence of fixes; when those fixes are connected the resulting lines may well not follow the object being represented.

{__} Set up: U.S. State Plane, Kentucky North Zone, Survey Feet. Display Not in Feature data with a middle-sized red dot. Open M1 12922A.COR in the folder __:\GPS2GIS\FARMHOUSE. Open the TIFF file Pat_S.tif in that same folder. Zoom up on the last 10 or so fixes. Note that these seem to be pretty much right on the country road—within six feet or so. If you measure the distance between the fixes you get about 200 feet, which was what the datalogger was set to receive. If you now change the display to show the fixes joined you get a somewhat different impression of the accuracy, as the red line goes slicing across fields and fence rows. So if you want to represent curvilinear features you (a) can't do it exactly, and (b) should use short distances between fixes. The distances can't be too short, however, because errors will be recorded and file sizes will become quite large.

Community Base StationInformation Form

Base station name: _____

Base station location: _____

Approximate distance to the location of your files _____

Web URL and/or FTP address:_____

Initial character of .SSF or .EXE files from this base station: _____

Contact Person & telephone number:_____

Account name(s): _____

_____

Password: (record it elsewhere)

Procedure for downloading files: _____

_____

_____

_____

Notes: _____

_____

_____

_____

_____

_____

5
AreView, ArcData, and GPS

IN WHICH you learn to use a part ofESRI's ArcView software,and use input from the ArcUSA database and GPS files.

OVERVIEW

What GIS Is

The title of this book, *The Global Positioning System and GIS,* implies that you can find information here on how to use GPS to develop data for a Geographic Information System. Since you are now well versed in the elementary theory and practical use of GPS we are now ready to discuss how it can be used as input for GIS. Let's look first at two distinctly different definitions of GIS.

From an organizational, societal point of view one definition might be: A Geographic Information System (GIS) is an organized collection of computer hardware and software, people, money, and organizational infrastructure that makes possible the collection and storage of geographic and attribute data, for purposes of retrieval, analysis, synthesis, and display to promote understanding and assist decision-making.

But from a software and functional point of view: A GIS is a marriage of

1. a (geo)graphic database and
2. an attribute (frequently relational, perhaps multimedia) database. The combination of these two databases allows:

   - textual results from graphical queries,
   - graphical results from graphical queries,

- textual results from textual queries, and
- graphical results from textual queries.

The point I wish to make, from both of these definitions actually, is that geographic information and attribute information are closely linked in a GIS. It is the integration of these two that we seek. In this chapter you will see these two components put together after being collected separately. In Chapter 6 you will use data you collected in a GIS. In Chapter 7 we'll explore ways to collect both positional information and attribute information at the same time.

GPS and GIS

I have chosen to illustrate the process using software from ESRI (Environmental Systems Research Institute, of Redlands, California) because it is the software that is most widely used by serious GIS professionals, because it is the most comprehensive, and because once data are in ESRI product format they can be converted to many other GIS formats.

ESRI GIS Products and Terminology

ESRI makes several GIS products. Among them are:

ArcInfo[1]—an extensive, fully functional GIS which runs primarily on UNIX-based, workstation-class computers and on Windows NT machines.

PC ArcInfo—a personal computer (PC) product which is implemented on computers based on the Intel processors (80386, i486, Pentium, and so on). It is a subset of ArcInfo. There are versions which run in the Microsoft Windows environment and others that run directly under DOS.

Arc View[2]—a GIS system, based on a user-friendly *graphics user interface* (GUI, pronounced gooey) used for viewing and analyzing GIS data. In this chapter you will learn the rudiments of Arc View and combine GIS data with that generated by a GPS receiver.

ArcCAD—another PC version of ArcInfo which runs under AutoCAD® (by AutoDesk®). Its primary use is providing ArcInfo functionality for those who wish to operate in the AutoCAD environment.

A number of terms are important to understanding ESRI products:

Shapefile—A data structure (a set of files, actually) that stores geometric elements—such as points, lines, and polygons—that represent geographic features like parking meters, rivers, and ownership parcels. Associated with the geographic features are relational database tables that contain textual information about the features. The shapefile is the fundamental data structure of Arc View, although Arc View can take in and process other ESRI data structures.

Coverage—A data structure (embracing many of the characteristics of the shapefile, but more complex and powerful) which serves as a primary data structure of ArcInfo. While a given shapefile may store only points or lines[3] or polygons, coverages may store combinations of these and, in addition, store the relationships between them. Many of the data sets that are available for ESRI products—from ESRI itself and from third-party vendors—is in coverage form. Coverages are described in detail in Chapter 6, but they will be used in this chapter as input to Arc View because we will use some "canned" data in coverage form.

We Start with ArcView

ArcInfo is complex. It is loaded with "functionality." It has extensive data development, analysis, and display capability. Some of these capabilities are found in modules, or subprograms, of ArcInfo. In particular, when you want to display spatial data you use a module called ARCPLOT.

While ARCPLOT provides a very powerful, well-tested, and comprehensive set of mapmaking tools, its format does present problems for the new GIS user. ARCPLOT is a command-driven system whose (admittedly vast) features and capabilities have been developed in a rather additive fashion over the last decade or two. The structure of ARCPLOT's command language, therefore, is less than intuitive, and a good deal of preliminary study is needed to use it effectively.

ArcView—developed by ESRI largely to address the issues of ArcInfo's complexity and lack of a GUI, and to maintain ESRI's

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[1] ArcInfo WORKSTATION version 8.1. ArcInfo Desktop (ArcGIS 8.1) is not described.

[2] Described herein as Arc View 3.2, not Arc View 8.1, which is part of ArcGIS 8.1.

premier spot in the burgeoning desktop mapping market—is a menu-driven system designed for Microsoft Windows and UNIX platforms. It retains much of the power and flexibility of the various modules of ArcInfo, but operates in a more user-friendly environment.

ArcView exists in several versions. It is ArcView 3.1 (or greater) that is described in this text. The text has been tested with both the Windows and UNIX versions of ArcView 3.2.

Integration of GIS Activities

Besides its user-friendly environment, Arc View serves to integrate many of the activities associated with GIS and desktop mapping. ArcInfo couples a graphic database with a relational database. Arc View maintains this relationship, and adds user-friendly features to it. Within Arc View is easy and efficient mapping capability, the ability to include charts in the graphic output, and macro language programming support. There are analysis functions as well. Arc View uses not only the shapefile, but handles the standard ESRI coverage as well.

Learning to use Arc View is somewhat like learning to ride a bicycle. I can attempt to describe to you how to lean the bicycle into the inside of a corner as you turn the handlebars (ever so slightly, now) and try to sit directly upright with respect to the bike, and…But the truth is that the interactions of the various forces and mechanical components are so complex that you simply have to go through the experiences (even falling off) to truly "understand" the process. And so it is with Arc View. So I will briefly describe the overall structure of the program and then we will launch into using it, with some GPS data, and some from ArcData.

The Components of ArcView

For the GIS professional or student perhaps the greatest hurdle to a quick learning of ArcView is getting used to the nomenclature and the interweaving of the various components. The diagram of Figure 5–1 may help.

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[3] Called "arcs," in their more elaborate form in coverages. They are fundamental—as the name ArcInfo implies.
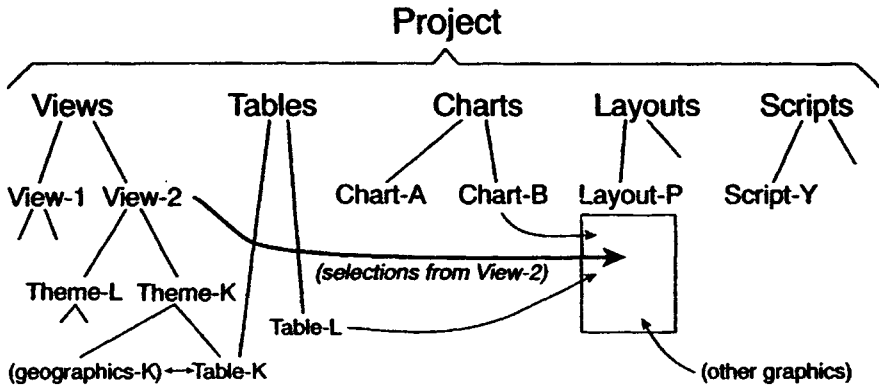
Figure 5–1. Portion of a typical ArcView component arrangement.

An ArcView **Project,** much like a Pathfinder Office project, constitutes an amalgamation of the data and information associated with a major GIS endeavor. From a graphic point of view, a Project is a window from which a user can access and control the data relevant to the endeavor. From a software aspect, a Project is a single computer file which "points" to other files and sources of information.

Each Project window contains five basic types of components, shown on the second line in Figure 5–1: Views, Tables, Charts, Layouts, and Scripts. The icons for each component type are always available at the side of the "Project" window; each component operates inside its own window, with a set of menus for the particular type. While any number of component windows may be open in a Project, only one of them will be active at any given time.

Because this chapter will place virtually all its emphasis on Views and Tables, I want to describe the Charts, Layouts, and Scripts now, briefly, so we can move on to the issues on which we will spend the most time.

Scripts are text files. They contain instructions for the ArcView macro language called Avenue. Avenue is used for more advanced applications, or when an organization wants to set up a particular operation for an ArcView operator to do a particular task. You could use ArcView for a long time and not write Avenue scripts. It's the day you notice that you are doing the same operation over and over again, with different data, that you may decide to learn the programming language Avenue, and write a script to save

yourself time and avoid mistakes. Avenue is an "object-oriented" programming language, which means that it is capable of handling quite sophisticated data structures, as well as doing the usual complex operations that high-level programming languages do.

Charts are just that: graphic representations of data. You may choose pie charts, line graphs, bar graphs, and so on. The data for charts comes from tables—essentially those relational database tables that form "half of a GIS. GIS capabilities are being sought by desktop users, who need to be able to integrate such information into presentations. So ArcView provides this tool that lets users present facts and the results of analyses. The products developed by Charts may be integrated into a map, or used by themselves.

Layouts constitute the mapmaking capability of ArcView. Here you can combine graphics, "geographies," text, graphs, and other data. Examples include elements you create with the drawing tools provided—ellipses, arbitrary polygons, rectangles. Layouts may contain text in a wide variety of sizes and fonts. Special symbols unique to maps are easily included: north arrows, scale bars, legends, and so on. But mostly, layouts contain geographic information in map form.

Views

As may be inferred from Figure 5–1, a View is central to work with any data, whether graphic or textual. The fundamental elements of any Arc View session are its views and their corresponding tables. Views are used to display, manipulate and analyze geographic data, which is accessed from various sources such as shapefiles, coverages, and satellite photographs. Views have associated tabular data that imply spatial (or other) information, such as zip codes and census tracts (or owners' names and delinquent tax amounts). Both the spatial and tabular data can be read locally from disk or CD-ROM, or across a network from distant data sources.

A *theme* consists of geographic and attribute data that are derived from a shapefile, coverage, or other ESRI data structure (such as GRID or TIN). **Themes serve as the building blocks of a view.** A theme is a set of geographic features which have characteristics in common. So, for example, you might create a land-use view that consists of one theme representing roads, one

theme representing soil types, one representing rivers, and one representing sewer lines.

The themes in a view do not actually store geographic data files or attribute files; rather, they access that data from specified sources each time you initiate work on a view containing the theme. The theme tools manipulate and display the source data; any change made to such source data is automatically reflected in the themes comprising your view.

In addition to manipulating the display of the themes in your view, you can perform various types of spatial analysis based on relationships within a theme or relationships between themes.

Operations on Themes and Views

There are many ways to manipulate a theme, once it is part of a view. For example, you can:

- change the visual appearance of the features of a theme;
- select features according to their location by pointing at them with the mouse cursor, or by drawing shapes around them;
- select features on a view by selecting their records from the associated table, either by designating individual records or specifying values of attributes; and
- select features based on relationships to other features in the theme, or in other themes.

To appreciate the power and ease of use of ArcView, you must experience it. You will do that, after just a brief description of one of the data sources we will use in the projects of this part.

The ArcUSA Database

ArcUSA is a compilation, distributed on CD-ROM, of spatial data related to the coterminous (48 states) United States. It contains many themes such as roads, lakes, counties, and so on. The data are in the form of ESRI coverages (both Windows and UNIX versions are provided) so they may be used directly and immediately in both ArcInfo and ArcView. The most detailed data contained on the CD are those that you might expect to find on a 1 to 2 million (2M) scale map. Of course, GIS data are usually referenced by their real-world coordinates, so saying that a GIS dataset is of scale "2M" is simply an indication of the level of

resolution; **GIS data have no scale**. ArcUSA, at the highest level of its data structure, consists of three large directories. The separate 1:25M database serves the need for general information at a small scale, and as an index to the more detailed coverages. The other two directories, at the 1:2M scale, each contain the same data. The most fundamental data, which we will bring into this project, use latitude and longitude, in decimal degrees, as spatial coordinates. The other directory stores data in the Albers Conic Equal-Area projection, which works well for viewing, but not for combining with other data which are not in that projection. Within each directory are coverages, most of which span the entire country. Some coverages, however, cover only a portion of the United States, due to their size and level of detail.

   ArcUSA is a good data set to illustrate principles but if you want the most current national or international geographic data you should explore several sources. One really good place to start is on the Internet: http:// geographynetwork.com contains a plentitude of free data, government data, and commercial data.

STEP-BY-STEP

PROJECT 5-A

Seeing GPS Data with ArcView

We now turn to using ArcView to examine GPS data together with GIS data from other sources, including the ArcUSA database. In this project, you will bring up a GPS track of a vehicle that traveled from Lexington, Kentucky, south on Interstate 75, west around Knoxville, Tennessee, to a bank of Fort Loudon Lake (the Tennessee River) near Fort Loudon Dam. You will see this track in the context of the counties of Kentucky and Tennessee, major roads and hydrological features. The GPS file that was taken was named I090317A.SSF. From that file a shapefile of the same name[4] was generated, using latitude and longitude in decimal degrees.

   A word of caution. What follows is not a comprehensive tutorial of Arc View. There is much, much more to the software than is demonstrated here. Further, no attempt is made to cover the features shown in detail. Rather, this is a "show and tell" session that will let you see some of Arc View's capabilities. If you absorb
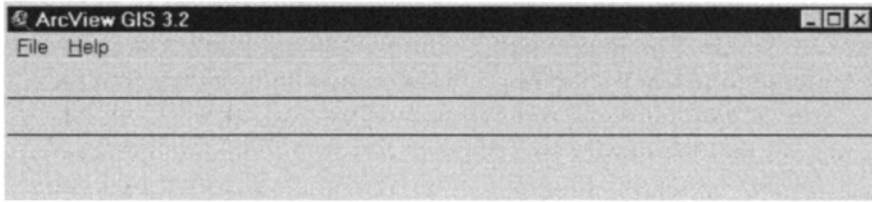
Figure 5–2. The most basic ArcView Window.

(maybe even take notes on) what you do, this session will give you some facility with the program.

Starting ArcView

{__} To start the process, enter the ArcView program from Windows or UNIX. Your instructor may have provided information on how to do this.[5]

   {__} A window entitled "ArcView GIS x.x" will appear. Within it a window named "Untitled" will also appear; this is the Project window. (If any other windows appear, cancel or dismiss them.) Enlarge the ArcView window to full screen using an icon control on the title bar. Downsize the window by clicking in another title bar control. Now make it full size again by double-clicking on the title bar. You want to start ArcView at the most basic level, so you will close the "Untitled" project window. Either of two ways may be used:

- click on the "magnifying glass" in the upper left corner of the "Untitled" window that is within the ArcView application and click on "Close" in the drop-down menu; or
- click on the "X" in the upper right corner of the window.

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[4] The latest Trimble software generates shapefiles of the name posnpnt.shp rather than the name of the GPS input file (e.g., I090317A). Once in ArcView the name can be changed back to the original SSF file name.

[5] The instructions in this chapter apply to Windows. They must be modified for UNIX systems; in particular, there is no "C" drive, (or __:\ as you have used in Pathfinder Office) and the delimiter "/" is used in UNIX path designations, contrasted with the "\" delimiter in Windows. There are other differences—none significant.

If you are asked if you want to save something, say No.

Be sure not to close the window titled "ArcView" or you will have to restart ArcView and wait while it reinitiates.

When you have finished, the top of the screen should look like Figure 5–2.

Getting Help

{__} ***Getting detailed information about the use of ArcView is facilitated by an "on-line help" feature.*** Click "Help" to bring up the help menu. (By the way, "hot-keys" [Alt+a letter, in this case Alt+h] work in ArcView as well as the GPS software.) The Help system is pretty involved. It is worth spending half an hour or so simply exploring it. Start by selecting "How to Get Help" from the menu below the title. Check this out. Note that you have at your disposal a Glossary of ArcView terms. Under the Help window File menu you can print out a topic. Edit lets you copy selected parts of a Help file for pasting somewhere else (e.g., a text application). You can "bookmark" particular topics that you might want to return to later. The Options menu lets you keep the Help window on top of the desktop. Also you may display a History of the help topics you have accessed during this ArcView session, so you can go back to one of them with just a click.

{__} Click on "Help Topics." Among the features here are:

- a table of contents of the Help files. Double-click (or pounce) on a book or topic to open the associated file.
- a way of searching the Index, which is a list of words the makers of the Help system decided you might want to find.
- a searching facility (Find) which searches the entire set of Help files for any character string you specify.
- a "Back" (to the previous topic) button.
- hypertext capability. Some text strings hide other, explanatory text. These text strings are frequently, but not always, underlined and in color. The screen pointer changes to a hand when placed over this text; when you click on the text you get more text. Arc View calls this a "Jump." To highlight all the hypertext-sensitive character strings in a window, hold down Ctrl and press Tab; to highlight each string, in order down the page, repeatedly press Tab.

{__} *Cancel "Help."* Exit from File or click the "X" button on the upper right corner of the window.

Starting a New Project...and Saving It

{__} Click on the only other Arc View menu item: "File."[6] Click on "New Project." A window with the name "Untitled" will appear. See Figure 5–3.

   {__} *Start to save this empty project with a new title:* From the "File" menu (note that the menu has changed, now that you have a project opened). Select "Save Project As...." A window of that name appears.

   (Recall: The following instructions apply to Windows. They must be modified for UNIX systems; in particular, there is no "__" drive and the slashes tilt the other way. Further, UNIX is case-sensitive. So when the text refers to "GPS2GIS" you may need to use "gps2gis"; "LXKX_yis" may be "lxkx_yis".)

   {__} In Windows begin by selecting the "__:" disk drive by clicking in the "Drives:" box. (The little "down arrow" icon associated with the box indicates that options may be chosen.) Use the slider bar to look at all the available drives. Click on "__:".

   {__} *Put the project into the GPS2GIS\LEX_KNOX directory:* Under "Directories" click on the "__:" folder. This will bring up all the subdirectories under the root. (If they don't appear, double-click on the "__:" folder.) You can scroll through them (using the page and arrow keys—the entries are in alphabetical order) to find "GPS2GIS."

   (You can make the process faster by highlighting any directory in the window, then typing a "g," which will take you to the top of the entries beginning with "g," typing "g" again will take you to the next entry beginning with "g," and so on.) When you locate "GPS2GIS," highlight it and press enter (double-click works also but is dangerous in this particular operation, for reasons to be explained shortly) to bring it to the top. It will show up directly under "__:\". The complete pathname, to which you will save the project, will also be shown under "Directories:"

   {__} Click in the "File Name:" box. After clearing out any text already there (using delete and backspace), type the name

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[6] In Arc View, and Windows and UNIX in general, there are usually several ways to do any single thing. For example, Alt-F works here instead of "click."
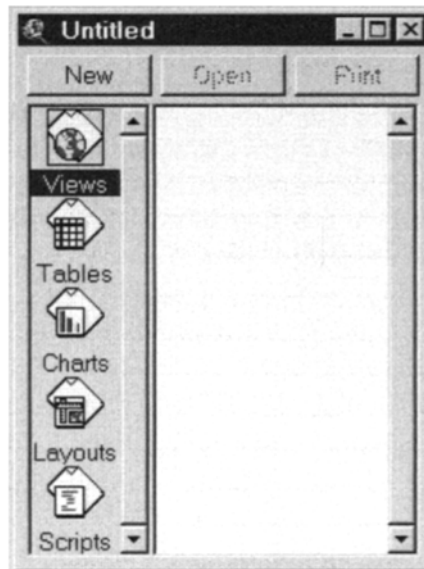
Figure 5–3. The ArcView Project window.

"LXKX_yis" (where "yis" stands for your initials, up to three) but don't hit enter yet. Now click "OK." The project "LXKX_yis.apr"[7] will have been saved to the directory C:\GPS2GIS. ("apr" stands for "Arcview PRoject") (It is dis concertingly easy to save a project in the wrong directory. If you just tap "Enter" without the correct name being under "Directories," or if you double-click on a folder that is the last one in the list, then ZAP— the project goes to that directory, correct or not. And since it is standard practice to double-click on folders to see what other folders are in them, it's easy to make a mistake. And it is not particularly easy to delete a project from the wrong directory. But at least you get to make the mistakes using an empty project.)

{__} Dismiss the project window entitled "LXKX_yis." You may be asked if you want to save changes. Since you just saved the

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[7] Note that we use lowercase letters here, for compatibility with the presentation given by ArcView. In Windows, we have stored the file LXKX_yis.APR to the directory __:\GPS2GIS\Lex_Knox. Inside ArcView the computer considers everything as upper-case, regardless of its appearance on the screen. ArcView may show lowercase letters, but the names used are not case-sensitive.

project, you do not.[8] You should be back to the basic ArcView window with only "File" and "Help" as menu items.

Opening a Project

{__} Select "File" and "Open Project," which is the way to bring up a previously saved project.

{__} In the "Open Project" window you go through a procedure much like the one you used to save project LXKX_yis. You select the drive and directory, and file name. In this instance, ArcView probably will have made it easy for you by providing as defaults the drive, directory, and name of the project you just saved. Don't be content with this. Experiment with all the options the window has to offer. Click on the arrow under "List Files of Type" to be certain you will be bringing up files of type "*.apr." Make the drive letter say "a:". (If there is no disk in the "a:" drive, abort the request.) Then choose "__:" again. Under "Directories" double-click on the "__:" folder. Then click on the "GPS2GIS" folder and hit enter. Now in the subwindow under "File Name" you should see (or be able to scroll to) "lxkx_yis.apr." Single-click on this, so that it appears directly under "File Name." Now everything is the way you want it, so click "OK." The project window, entitled "lxkx_yis.apr," will reappear. Along its left side will be icons called:

- Views
- Tables
- Charts
- Layouts
- Scripts

{__} Only one of these icons may be active at a given time. The View icon has a box around it and its name is highlighted. Make "Charts" active with a single click. Now make "Views" active again.

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[8] Incidentally, an "apr" file is just a text file. You can open up LXKX_yis.apr with a text editor (e.g., WordPad) if you are interested in looking at its construction. An "apr" file does not contain data as such, but rather the pointers, or paths, to the data. Therefore, if the data changes, and later you open the project, you will see the new data. On the other hand, if you move the data to another folder or machine you will leave ArcView wondering where it is and asking you about it.

{__} Review the ArcView structure figure in the preceding section. Recall that a project may contain views, tables, charts, layouts, and scripts. A view contains themes.

Initiating a View

{__} **Open a new view:** With the View icon active, click "New." Lots of things happen. A window appears, titled "View1." Also, two rows of icons appear across the top, just below the menu bar. They are called the **button bar,** on the upper level, and the toolbar, and we will make use of them shortly. (Briefly, the button bar invokes actions. The toolbar sets the tool you will be working with until you select another.) At this point you have several areas of the screen with which you can control ArcView. To summarize, they are:

• the menu bar (at the very top of the ArcView window),
• the button bar (next bar down),
• the toolbar (down again), and
• the icons representing the elements of a project (arrayed vertically down the left-hand side of the Project window).

{__} A window that is active has a colored background in the title bar. You can make a window active by single-clicking on the title (or anywhere on the title bar). Make the Project window "lxkx_yis" active. Notice that the button bar changes and all icons on the toolbar disappear. Now make the "View1" window active.

{__} As you know, you can move a window by dragging its title bar. Move "View1" so that it does not overlap "lxkx_yis." A window's size may be changed by dragging a border or a corner of it. Enlarge "View1," making it tall, so it fills the right side of the screen. (By the way, it is not a good idea to maximize a window in ArcView. And don't cover up the Project window completely—you'll wonder where it went.)

Views and Coverages: Adding a GPS-Based Theme

{__} **Bring the shapefile named i090317a.shp into the "View1"window:** Move the cursor (a pointer) to the menu bar and choose "View." Click on "Add Theme." Look in the __:\GPS2GIS \LEX_KNOX\ EXPORT directory for the shapefile. When you properly select that directory the file folder icon will appear as

open and names of shapefile(s) will appear in the text box to the left. Single-click directly on the map icon next to the name I090317a.shp. Now click "OK." The "Add Theme" window will disappear and the shapefile name "I090317a.shp" will appear in the Table of Contents (referred to hereafter as the "T/C") of the View1 window.[9] Also, you will see a fat dot in the T/C, which is the symbol that will be used to plot the points of the shapefile (which we will call a "theme" when it is opened in Arc View). Click on the little box next to the theme name. A check mark will appear there, and a solid line (actually composed of points representing the GPS fixes) will show up in the graphic area of View1. Please see Figure 5–4. This line represents the sequence of GPS fixes taken by the antenna of a car driven from Lexington, Kentucky to near Knoxville, Tennessee. The check mark next to the theme name means the theme is to be drawn in the View window. A checked box means the theme is on; unchecked is off. Turn the theme off and on a couple of times.

Editing the Legend

The dot that represents each GPS fix is so large that it overlaps the adjacent ones. We want to use a smaller symbol to represent the individual GPS points. Further, the color of the dot was picked "at random" by Arc View; you will change that also.

{__} From "Theme" on the menu bar, choose "Edit Legend" to bring up the "Legend Editor" window, which will let you change the characteristics of a plotting symbol. Double-click directly on the circular symbol in the "Legend Editor" window. A window entitled "Marker Palette" appears. (You may want to move this window and enlarge it to see what you are doing.) Please see Figure 5–5. Click on the paint-brush icon to change the title to "Color Palette." Single-click on bright red and click "Apply" in the Legend Editor window. Note the change of color in the display.

{__} In the "Color Palette," click on the "push pin" to change the title back to "Marker Palette." Select the square symbol at the top of the middle column. In the box designated "Size," click the size

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[9] You selected i090317a.shp (note lower case "l") but I090317a.shp (note capital "I") appeared in the T/C. Just remember, in Arc View, the case of file names is unimportant: a letter is a letter, regardless of whether it is upper or lower case. This is true even if you are using Arc View on a UNIX machine, although UNIX itself is sensitive to upper and lower case.
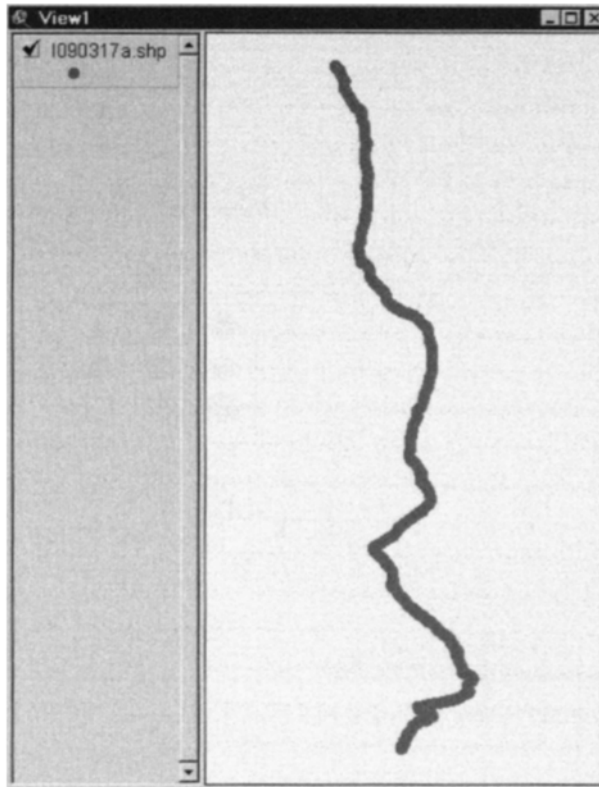
Figure 5–4. A GPS track—Laxington to Knoxville.

drop-down menu to get a list of possible sizes. Pick 4. Click "Apply" to plot the data with this new symbol size. If you get confused, click "Undo," which changes things back to the way they were the last time you clicked "Apply." If you get really confused, close (dismiss) the editor and palette windows and start again.

{__} It may not be obvious, but you now have a thin string of red boxes in the view window (we'll look at zooming in Arc View later), so dismiss the legend and palette editors.

Projecting Coordinates

Had the earth been formed as a cube instead of a quasisphere, many things regarding representation of locations and features on it would be simpler. (Of course, many other things would be more complicated, but here we are just concerned with methods of representation of features on the earth's surface.) The coordinate
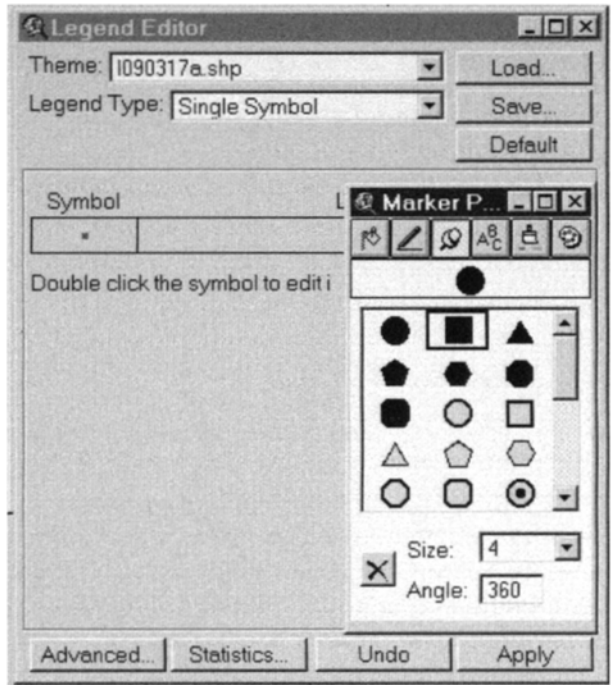
Figure 5–5. Legend Editor & Marker Pallet windows.

system that works best to represent a single location on earth is a spherical coordinate system. It can be applied perfectly, producing no distortion. Unfortunately, if you have to deal with, say, two point locations, the mathematical formulas for determining the distance between them, or the direction one must travel to get from one to the other, are complex. For many reasons, it is useful to represent areas of the surface of the earth on a flat sheet in a Cartesian coordinate system. The distance and area formulas are simple; the medium of display (paper) is convenient. (A model globe, which could provide theoretically complete accuracy of representation, distance, shape, and size, would have to be astoundingly large to provide any reasonable level of detail for human-scale activity.) When you make a transformation (called a projection) from a spherical system to a Cartesian one, you inevitably introduce inaccuracies in the locations of points that were correct in the spherical coordinate system. So when dealing with large areas of real estate you are always caught in the dilemma of choosing (1) exact representation or (2) distorted

representation which allows easy calculation and convenient display.

The image in the View—projected onto the (almost) flat screen of your monitor—is in latitude-longitude decimal degrees. (The coordinates are displayed toward the upper right-hand corner of the ArcView window.) Such images are wildly distorted because nowhere on earth (not even at the equator) does a degree of latitude represent the same distance as a degree of longitude. You cannot tell that this GPS track is distorted, because it is basically a line running from north to south. But if we put other data with it the distortion would become apparent. You will therefore change the view so that it shows data in Universal Transverse Mercator (UTM) coordinates. In UTM there is also distortion, but the effect is much reduced, especially over small areas.

{__} Make certain the mouse pointer is a simple arrow by choosing the arrow symbol (it is on the toolbar, second from the left). Now slide the pointer around on the view. Note the coordinate values, reported on the right top of the screen, are something like –84.00 (for the east-west coordinate)[10] and 37.00 (for north-south) toward the center of the view. These are the longitude and latitude, respectively, in decimal degrees. To reduce the distortion, you will convert the picture of the data you see, in the "View1" window, from the spherical coordinate system (the lat-lon graticule based on degrees and decimal fractions of a degree) to the UTM rectangular coordinate system for zone 16. The UTM units will be meters.

{__} From the "View" menu, choose "Properties." Click on "Projection." A "Projection Properties" window should appear. Please see Figure 5–6.

{__} Click in the box labeled "Category" to get a list. Choose UTM — 1983. Under "Type" choose Zone 16. (This is the UTM zone that contains the route delineated by the GPS fixes.) Note that the Central Meridian (the north-south line that bisects the zone) of the zone is 87 degrees west (–87°). Leave the standard option checked. Okay the "Projection Properties" window.

{__} Back in "View Properties" do not change "Map Units" (from "meters") but do change "Distance Units" to kilometers. Choose a

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[10] This western hemisphere longitude designation may also be represented as 84°W (for West) in other systems and software. The only problem occurs when you leave off both the minus sign and the W (or use both of them—which makes it East again).
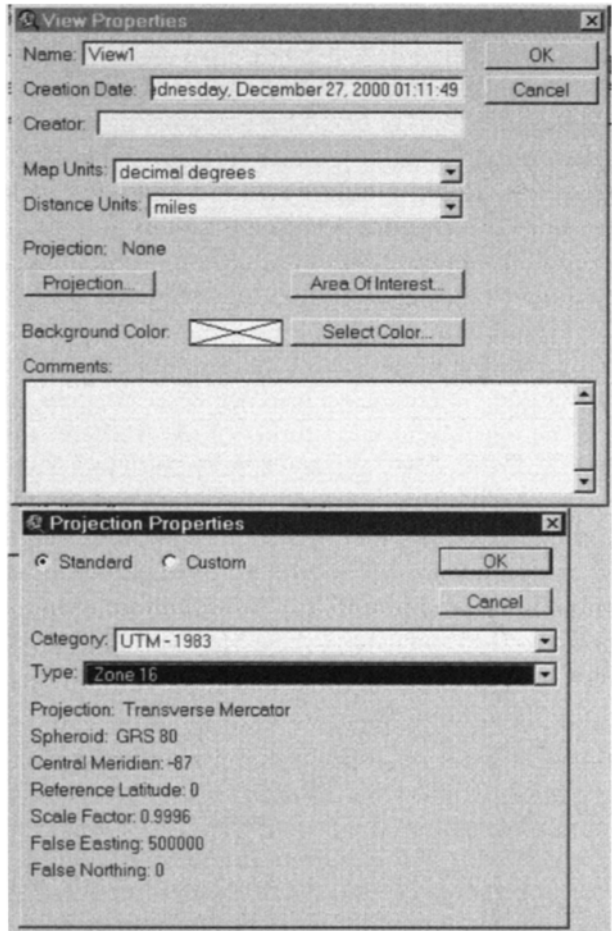
Figure 5–6. View & Projection Properties window.

lime-green background color, just to remind yourself that the display is now in a different projection. Click "OK."

{__} Again slide the pointer around the view. Note that the coordinates toward the center of the window reported now are approximately 750,000 for the horizontal (that makes it 250,000 meters east of the central meridian of (–87°), right?) and 4,100,000 meters north of the equator for the vertical. **It is important to understand that theoriginal data have not been converted—they are still in decimal degrees—but their visual representation in "View 1" has been alteredto reflect the UTM coordinate system.**

{__} Click the title bar to make the lxkx_yis.apr window active. Open the "File" menu by a single click. Move the cursor up and down the menu, noting that each highlighted menu item is explained in more detail at the bottom of the screen in a "message bar." When you have finished exploring, choose "Save Project" with a click. Again note the bottom of the screen for information.

Adding a Theme from ArcUSA

{__} Make the "View1" window active. In the "View" menu, choose "Add Theme." (Or use a shortcut: the second button from the left on the button bar performs the same function.) Construct the path to an ArcInfo **coverage** named "Cty2m" by doing the following: Choose the drive "__:" (in Windows only; UNIX doesn't have drive letters). Pounce[11] on the "__:" file folder. Find the "GPS2GIS \Lex_Knox" file folder and double-click on it. Pounce on "arcusa." Pounce on "arcusa_d." Pounce on "usa_2mg"—the two-million-scale dataset in geographic (decimal degrees) format.

{__} In the left-hand part of the Add Theme window, find the file-folder-map-icon combination next to the name "Cty2m"; this represents a subset of the counties in the United States. A theme may be an ArcInfo coverage instead of a shapefile. A coverage might have both polygon and line features, as well as annotation. It gets a little subtle here. Carefully **single**-click directly on the icon **next** to the name. The folder should open to reveal its contents. See Figure 5–7.

Now single-click the icon again. Note that clicking like this opens and closes the folder. When it is open you can see what is in it. In this case, what is in it are geographic data sets labeled "polygon," "arc," and "labelpoint." With the folder open, click on "polygon." Then click "OK." After a brief time, "Cty2m" will appear in the T/C, along with a colored, solid rectangle that indicates that the theme is a polygon (areal[12]) one.

{__} Turn Cty2m on by clicking in the box next to its name. Note that, after a bit, a number of polygons appear, representing counties which surround the GPS track. The GPS track itself does not appear, however. The reason is that it has been covered up by the polygon features. But a nice characteristic of ArcView is that

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[11] Recall that a "pounce" is a selection, followed by pressing Enter, or is a double-click.
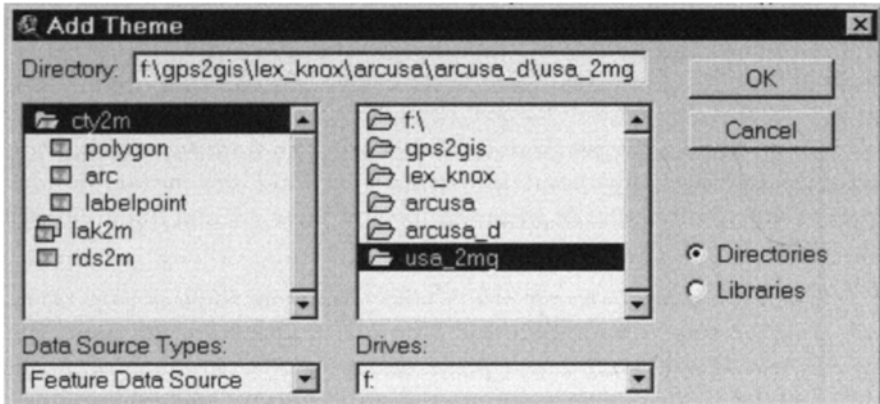
Figure 5–7. Adding an ArcInfo coverage as an ArcView theme.

you can specify the order in which themes in the T/C are drawn, and therefore control what themes are painted "on top of other themes.

{__} ***Draw the GPS track on top of the counties:*** Reverse the order of the two entries by placing the cursor on the T/C entry "Cty2m." and dragging it "south" of the "I090317a.shp" entry. View1 will be re-drawn, showing both themes.

The priority for drawing themes is directed by their order in the T/C. First, the theme at the bottom of the T/C list is "painted" on the view. Next to be painted is the theme second from the bottom, and so on. (Generally you would want to paint areal themes first, linear themes next, and point themes last.)

Themes in the T/C must be either on or off (drawn or not). They must also be active or not. A theme is active if the area in which its name and symbol appear is raised. You make a theme active by clicking on its name. A theme must be active for certain operations on it to take place (e.g., editing its legend). The importance of making a theme active—the **right** theme active—is illustrated next.

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[12] "Areal" is an unfortunate adjective meaning pertaining to "area." The spelling might lead you to believe that it means "not real" (compare with atypical or amoral). When pronounced, it sounds like aerial, as in aerial photography—an artifact not unknown to our profession. Myself, I'd join a movement to ban the word and find a substitute!

Identifying Particular Features of a
Particular Theme

{__} Make I090317a.shp active. Make Cty2m active—which makes I090317a no longer active. (More than one theme may be made active at a time, but this is a more advanced maneuver. For the moment, know how to make a single theme active, and how to make it visible.)

{__} With Cty2m active and on, move the pointer to the "identify tool" button, which is at the extreme left of the tool bar.[13] Click. Note that the button appears to be pushed in. The purpose of the "Identify Tool" is to let you query the table entry for a particular feature in the active theme. Move the pointer into the graphic part of the view window, to the county in which the GPS track starts (the northernmost county).

{__} Note that the pointer has become a cross with a little "i" associated with it. Click on the county. Note that an "Identify Results" window appears. Please see Figure 5–8. Enlarge it vertically. From the window you can find out what the theme table (in ArcInfo it is a Polygon Attribute Table [PAT]) contains for the county selected. You will see the coverage's Ids[14] the county's FIPS (Federal Information Processing Standard) codes, state, county, and subregion names. You learn that the county is Fayette, in Kentucky; that the state FIPS code is 21, the county FIPS is 067, and the overall FIPS code is 21067, which indicates, if you did not already know it, how an overall FIPS code is assigned. You also see numbers for the Area and Perimeter. These units come from the table and are those of the data from the original coverage (decimal degrees), not the projected units (meters in UTM). (Linear units and Areal units in decimal degrees are almost completely useless.)

{__} Click on the county at the end of the GPS track. Loudon county, Tennessee? Click on the county just northeast of Loudon. It should be Knox. Note that you can examine the information for each of the counties you previously selected, just by clicking on the

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[13] Some actions of ArcView are invoked by using items from the various menus. Others are activated by command or tool buttons. And several may be invoked by either method.

[14] For those familiar with ArcInfo: The two IDs shown are Cty2m_ and Cty2m_ID (the internal and user IDs for that polygon). This particular coverage came from PC ArcInfo. Had it been a UNIX or NT coverage the IDs would have been Cty2m# and Cty2m-ID.
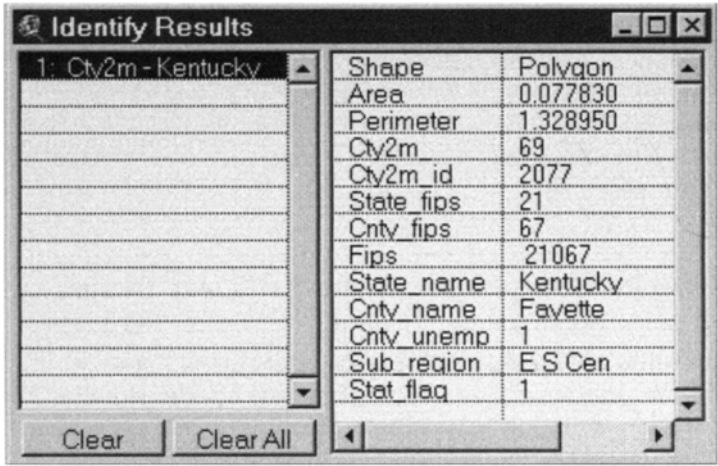
Figure 5–8. An "Identify Results" window.

entry name that appears on the left side of the "Identify Results" window. Dismiss the "Identify Results" window.

## Magnifying and Moving the Graphic Image

{__} ***Experiment with zooming and panning tools:***[15] Make certain that Cty2m is still the active theme. In the "View" menu select "Full Extent." You will see all the counties of Kentucky and Tennessee plus one county from each of the other states in the coterminous United States. (It takes a lot of time to draw all the counties in the United States, so I've abridged the coverage by selecting only the county in each state which is first alphabetically.) Pick "Zoom In" from that same menu. Click it to Zoom in. Zoom in again.[16] Each time the view is magnified so the scale gets larger. In the (misnamed) "Scale" text field you can see the **denominator** of the scale fraction. This denominator becomes smaller and smaller, which means the actual scale, which is a fraction less than one, is getting larger and larger—that is, closer and closer to 1.0.

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[15] For an explanation of what each tool does, move the pointer over a tool icon and observe the text at the bottom of the Arc View window.

[16] If you go back over this step this might be a good place to try out the "hot-keys." To repeatedly zoom in you could use Alt-V to bring up the View menu, then Alt-I, to zoom in.

{__} Select the panning tool (it's the seventh tool button from the left; it looks like a hand); use the hand cursor on the map to drag Kentucky (KY) and Tennessee (TN) to the center of the window.

{__} The fifth tool button from the left (a magnifying glass symbol with a "+" on it) lets you do a couple of things. If you make it the active tool and click on a point in the View, the image is zoomed up and the point you clicked on moves to the center of the new image. If you drag a rectangle on the window, the image initially within its area is transformed so that that image approximately fills the View window. This gives you considerable control over the amount by which you change the scale of the image. Zoom up on KY and TN. (If, at any time, you want to experiment with these features, you can take the View back to its Full Extent and rezoom and repan.)

{__} Make the I090317a.shp theme active. Under "View," "Zoom to (active) Themes." The entire GPS track should be visible, with some margins around it.

Selecting Features

Selecting features is an important aspect of ArcView. **Features in a thememay be selected from an active view or an active table.**

{__} Move the cursor over the Select Features tool (a rectangularish icon, fourth from the left side on the toolbar). Read the description at the bottom of the screen. Click on this tool. Make the Cty2m theme active. **Selection works only on active themes.** Experiment: select a county by clicking on it. It should turn yellow. (By the way, you should probably avoid the use, through the Legend Editor, of that bright yellow color for themes, since it is the ArcView standard for selected features.) Select some other county polygons. To select more than one county at a time, hold down the shift key while clicking.

{__} With the Select Feature tool, click on only Loudon county. In the View menu, pick "Zoom to Selected (features)." Loudon county should pretty much fill the width of the view window. If you zoom up on the eastern part of the county you should be able to see individual GPS fixes.

Adding Water

{__} In the ArcUSA database, find a **coverage** named "Lak2m." (Hint: choose "Add Theme" from the "View" menu or press the Add Theme icon on the button bar.) Add its polygon features as a theme to the view. Make its color a medium turquoise. Paint it on top of the counties, but under the GPS track.

{__} Use the magnify tool to zoom up on a rectangle that encloses both the land and water at the end of the GPS track. It appears from the image that the vehicle that carried the GPS antenna must have been amphibious: several points appear offshore.

{__} Use the measuring tool (it looks like a ruler with arrows and a question mark) to determine the distance from the shore to the furthest point on the GPS track. (Click on the tool, then on a point you want the distance from, then double-click on the point you want the distance to.) From the message at the bottom of the screen ("Length"), it appears that the antenna was a third of a kilometer from shore. In reality the vehicle stopped about 50 meters from the water. Where does the problem lie? The GPS track probably has its usual level of accuracy. (These are uncorrected fixes taken when SA was active so you can expect about 100-meter accuracy.) ArcUSA data are less accurate, however. They are taken from 1:2 million scale maps; if you read the manual that accompanied the data set you would find that lines may be expected to have an error of 1792 meters, or almost two kilometers. That would certainly more than account for the problem that we see with the GPS track and the lake.

{__} Zoom out, using the magnifying glass with the negative sign ("−") in it. As with the Zoom-in tool, if you click in the view, the point where you click moves to the center of the window and the scale changes. Also, with this tool you can drag a rectangle with the following characteristics:

1. The center of the rectangle will be the center of the zoomed-out window.
2. The area of the drawn rectangle approximates an area such that the entire existing view will all fit into that drawn rectangle. That is, the box you drag suggests the box that you want the entire currently-visible portion of the map to fit into. The smaller you make the dragged window the greater the degree of zooming out.

{__} Make the GPS track the active theme. Zoom to it. Rearrange and resize the View window so that it occupies the right half of the ArcView window. Narrow the T/C portion of the window by dragging the boundary between the T/C and the graphics to the left.

Bringing Up a Theme Table

With the identify tool you were able to see individual records of an active theme. You may also work with the entire Theme Table (in a ArcInfo coverage it's a Feature Attribute Table) of any given theme. You do that next.

{__} Make Cty2m the active theme. Under the "Theme" menu, pick "Table." The theme table of the polygon theme Cty2m will appear. (Move and resize this table so that it occupies the left half of the ArcView window.)

{__} Note that there are 293 records (look at the toolbar). Use the horizontal and vertical slider bars to examine the contents of the table.

Making Queries, and Looking at Text and Graphics

One of the outstanding features of a GIS is that it provides the user with the ability to: make queries of a graphical database and get the answers with text; and make queries of a textual database and get the answers with graphics. The following actions will demonstrate how easy this is in ArcView.

{__} Make the "View1" window active by clicking in its title bar. (You can usually make a window active by clicking anywhere in it, but if you click in places other than the title bar, you can produce unintended side effects!) Make the GPS theme (I090317a.shp) active. Zoom to (active) Themes.

{__} *Select a polygon from Cty2m:* Use the selection tool and click in the northernmost county that contains the GPS track to select that polygon. Note that it turns yellow. (If it didn't, I sort of caught you. Before you can use the selection tool you have to make the theme you want to select from the active theme. In this case you probably didn't make Cty2m the active theme. Try again.)

{__} Make the "Table" window active. Note that one record of the 293 is selected. That record will appear at the top of the window highlighted in yellow when you click the Promote button. The

record corresponds to the selected county. What is the county name?

{__} Use the "Find" choice in the "Table" menu to bring up a "Find" window. Type "Loudon" (no quotes). Both the record in the table and the graphical representation should become highlighted in yellow.

{__} Find "Knox." What state is it in? _____. Find "Knox" again. What state is it in? _____. Try to find "Knox" once more.

{__} ***Check out another way to get Help:*** Click on the button with the arrow and the question mark. This changes the cursor to a similar icon. With this cursor active, the next time you click on the ArcView window you will (usually) get information about the element your cursor pointed to. It works only once for each click on the help button. Click on some other button or tool (the Find tool you just used, for example) and read about it. Now click twice on the help button, so you can read about the Help Button.

{__} With the View window active, locate the button that is eleventh (11th) from the left border. It should look like a baggage tag. If it doesn't, point to it and hold down the left mouse button. Pick the baggage tag out of the drop-down list. This is the Label button.

{__} With the help button icon showing as your cursor, click on the Label button. You should get a help file named Label Tools. Peruse that file briefly, then dismiss it. Place the pointer over that 11th button and hold the left mouse button down. A drop-down menu will appear showing the choices you read about in the last step. Slide the pointer down the list and release it over the icon that looks like a baggage tag with a string attached. You have brought the Label Tool to the toolbar and made it the current tool.

{__} With the view and Cty2M active, select properties under the theme menu. (Or find the equivalent button and press it.) Select Text Labels. In the Label Field, scroll to Cnty_name and click it. Uncheck the "Scale Labels" box. Okay the choices. Now, since the Label Tool is active and, since the county name is the selected text label, if you click in a county, the name of that county will be added as **Graphics** to the view. Check out several counties. If you make the pointer the tool active you can click on a text label and move or resize it. You can also delete the selected graphics with the keyboard delete (Del) key. To delete all graphics, pick Select All Graphics under the Edit menu; press the delete key.

{__} Zoom to the extent of the GPS track. Make Cty2m the active theme. Using the selection tool, select all the counties that the GPS
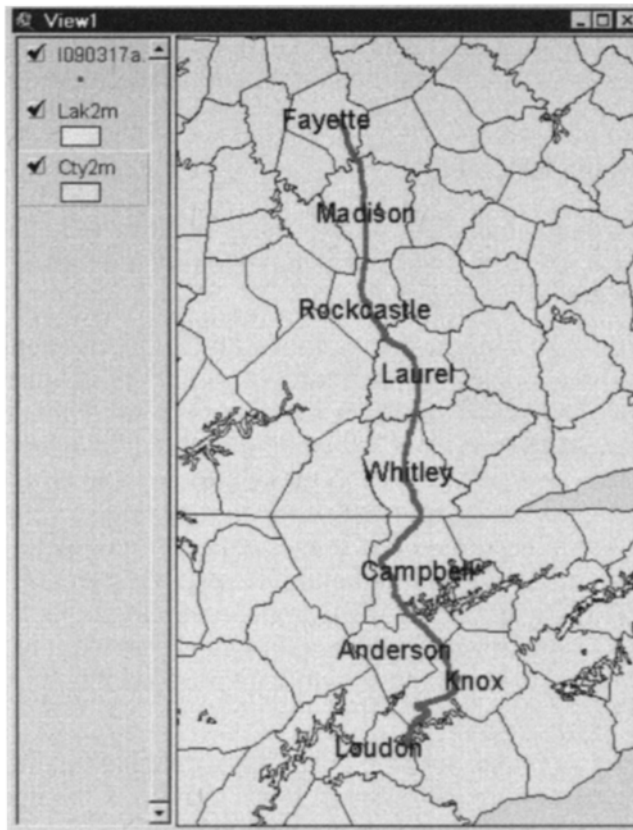
Figure 5–9. Labeled counties along the GPS track.

track runs through. Click Theme ~ Auto Label. An Auto Label window will appear. Make sure that Cnty_name is in the Label Field. Click OK. The result should look like Figure 5–9. Delete the labels using, this time, Theme ~ Remove Labels.

{__} Using the labeling, selecting, or identifying approaches described in previous steps, zoom out a bit and determine (and remember) the location of the Kentucky-Tennessee border. Then delete the graphics.

{__} Make the view active. With the selection tool, drag a slim, horizontal box that is contained entirely within several northern Tennessee counties, thereby selecting them. If you don't like the results, try again.

{__} Make the table active. Under "Table," pick "Promote" to bring all the selected records to the top of the table.

{__} Under the "Edit" menu, "Switch Selection." Note that the selected records in the table correspond to the selected polygons. Switch selections again. Then "Select None." Dismiss the theme table.

More Complex Selecting

The following actions demonstrate a fairly sophisticated selection technique. You will select the counties that the GPS track traverses in a different way than the method you used above.

{__} With the view window active, make I090317a.shp active. Under the "Theme" menu, pick "Table." "Attributes of I090317a.shp" should appear. Enlarge the table to fit the left of the screen. The table has an attribute named "Shape" that is remarkably dull. It also has attributes Gps_time (the time at which each fix was taken) and Gps_height (in feet above sea level). Despite some shockingly large errors, because these data are uncorrected and taken while SA was active, you can determine something from the height. Both Lexington and Knoxville are at about 1000 feet MSL. The Cumberland mountains lie between them. By scrolling down the table, can you tell how many hours out of Lexington the car reached the highpoint of its journey through these mountains? _____.

{__} Find the greatest number in the Gps_height field in a simpler way. Click once on the field name. It will darken. Click again. It will lighten. It is selected when it is darker. Select it. In the Field drop-down menu pick "Sort descending." Now the largest number in that column should be at the top. Was it the value that you found in the previous step?

{__} Again in the Field menu: pick "Statistics." Could come in handy, yes? You could select all the text with the mouse cursor, and cut and paste it in some other document (as I've done here).

   Sum: 712625.681
   Count: 682
   Mean: 1044.906
   Maximum: 2464.377
   Minimum: 186.908
   Range: 2277.469
   Variance: 150716.551
   Standard Deviation: 388.222

{__} Make sure that that table is active. Using an icon that you'll find on the _____ bar, sort the table with the Gps_time field, so

that the earliest time is at the top. Now examine the table; note that the sort didn't really work as you might like it to. 1:xx P.M. shows up before 12:xx P.M. To put the records back into their original order click "Refresh" in the "Tables" menu.

{__} Under the "Edit" menu, "Select All." This should highlight all the records in the table and highlight the symbols showing the GPS track as well. Dismiss this table, but leave the "Attributes of Cty2m" table up, and leave the GPS track selected.

{__} With the view window active and the Cty2m theme active as well, pick "Select By Theme" under the "Theme" menu. A dialog box appears. Set it up so that it selects features of the active theme that **intersect** the selected features of I090317a.shp. Make this a new set. To see all of what has been selected, zoom to selected features.

{__} Make the GPS track theme active. Under "Theme," clear selected features, so the track will reappear in red. (Yellow on yellow doesn't provide much contrast.)

{__} *Look at the records of the selected counties:* Make "Attributes of Cty2m" active. (Click on the title bar! If you click in the body of the window instead of in the title bar, you'll lose the proper selections.) How many counties were selected? _____. Verify this graphically. To look at all the records of the selected counties, promote the selected records—this time use the "Promote" button.

{__} Click on the record of Laurel county Kentucky using the select tool.[17] Note how all the other selected records and images become deselected. Clear all selections by picking "Select None" in the Edit menu.

Other Cool Table Operations

Several other operations may be done on tables. A few examples follow.

{__} Make sure that Attributes of Cty2m is the active window. Click on the attribute heading "Cnty_name." Note that it is highlighted: the black text is changed to white. From the Field menu, pick "Sort Ascending." Look at the effect on the table. (Note how many Virginia records there are in the "State_name" column,

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[17] The Select icon (when a Table is active) looks like the Pointer icon (when a View is active): a north-north-west pointing arrow. Same icon, different meaning in a different context. Be careful.

all with the same county name. Later in the exercises you will find out why.)

{__} *Select all the counties of Tennessee:* Begin to "build a query" either by picking the query-building tool (it looks like a hammer) or picking "Query" from the "Table" menu. A window appears which contains "Fields" (attribute names), "Values" (attribute elements), and operators such as ">=" and "not." The goal is to type or build the expression: ([State_name] = "Tennessee"). You could type it, but by double-clicking on the fields and values, and single-clicking on the operators, you can construct this expression. Once it is the way you want it, click on "New Set." The rows in the table that represent Tennessee counties will turn yellow. The graphic representation, "View1," will also show all Tennessee counties as yellow.

{__} Promote the selected rows to the top of the table. Page down through the table. Note that all the Tennessee records are at the top.

{__} *Use "Query" again to add Fayette county Kentucky to the selected set:* Use the delete key and/or the backspace key to remove the previous expression. Start with the paired parentheses and build the query ([Cnty_name] = "Fayette"). Instead of New Set, pick Add to Set. Promote the selected counties and examine the table, noting that it now includes Fayette County Kentucky. Dismiss the query building window.

{__} *Demonstrate the importance of having the correct theme active when you wish to work on it:* Make Lak2m the active theme. Under the "Theme" menu, pick "Clear Selected Features." Nothing happens, because no features of Lak2m are selected. Now make Cty2m the active theme. Again clear selected features. This time Fayette county and the Tennessee counties are deselected.

{__} Save the project. By this time you have seen a lot of ArcView — but there is much, much more. If you want to learn a bit more about it, including how it can be used to make thematic maps, do the exercises below.

Exercises

Exercise 5–1: The route from Lexington to Knoxville requires crossing the Kentucky River at Clays Ferry. Due to the volume of traffic, the two-car ferry was replaced some time ago; today a six lane bridge—part of Interstate 75—handles the traffic. That bridge

Figure 5–10. Displacement of bridge spans in orthophoto due to altitude differences.

is several hundred feet above the river. A GPS track across the bridge is not congruent with the bridge span, as you will see if you do the following:

{__} Make a new view: View2. In __:\GPS2GIS \Clays_Ferry\ you will find an image: CLAYS_FERRY.TIF. Add that as a theme and turn it on. Maximize ArcView. Maximize View2. Locate the bridge and zoom up on it, showing primarily the bridge and some highway at each end. Note that the bridge seems to bend toward the southwest.

{__} In the same folder you will also find Clays_Ferry.shp, which is the corrected GPS track of point representing fixes taken by a car crossing the bridge from the northwest to southeast, with a GeoExplorer taking "ALL" points. Add that as a theme as well. Make its legend a bright yellow circle of size 8 and turn it on. The result should appear as in Figure 5–10. Notice that the track of GPS fixes starts off with the car not only on the Interstate but in

the right lane. As the car enters the bridge, however, it seems to depart from the roadway, cross over to the northbound span, and then return to its original roadway. The data are accurate to two meters. Can you explain this phenomenon? _____

Exercise 5–2: By using the ability to sort records we can obtain different types of information.

{__} With the Cty2m table active, use the query builder to select all the records containing "Virginia" as the "State_name." Promote them. Why does the one county have so many records? (Hint: In the view, zoom to the selected features.) _____.

{__} Clear the selected set.

{__} Make a new set by selecting all Kentucky counties in the table. Notice that 121 records are selected, corresponding to 121 polygons. But Kentucky has only 120 counties, so one county must consist of two polygons. Can you find which one? _____. Select only those two polygons. Zoom to them. That county used to be one polygon before the Mississippi River changed its course.

{__} Clear the selected set.

Exercise 5–3: Arc View can generate thematic maps—maps that represent the value of some variable by shading or coloring polygons differently. The values used may be taken from a table for the theme. In this exercise you will use the attribute (field) named "Cnty_unemp," to make a thematic map showing the unemployment rate in the counties.

{__} Expand the View window so it is wider but not so tall. Do the same with the Table window. Select the counties of Kentucky from the table. Zoom to selected features. Clear selected features.

{__} Turn off all themes except Cty2m.

{__} Make the view active. With the Cty2m theme active, edit its legend (Theme ~ Edit Legend). The "Theme" will indicate Cty2m. As the legend type, choose Unique Value. Make the Values Field show "Cnty_unemp." When you do this, the "Legend Editor" will indicate a number of areal symbols, each with a value or range of values beside it. A degree of unemployment for the counties is given by a value ranging from 0 (no data) to 6 (high unemployment). Click apply and look at the map. To use colors other than those chosen by ArcView, click Fruits and Vegetables under color schemes and apply. An ugly map appears, with counties shown in wildly different colors. While you could determine the unemployment value in each county by look ing at the legend, you don't get an intuitive idea of the progression of the values.

{__} Try a different approach. Suppose you want to assign the "color" clear to the zero values (which appear in the field for states other than Kentucky). You want a light color for counties with a value of "1" for "Cnty_unemp." And you want the color to get increasingly darker for counties with higher unemployment. To do this, choose Graduated Color for the Legend Type; pick Beige to Brown for the color ramp. Apply. This almost gives us what we want.

{__} Note that there are seven categories of unemployment (designated as 0 through 6), but only five symbols are being used. Rather than combine some categories, as has happened, you may want to have a symbol for each category. Click "Classify" to bring up a Classification window. Make the Type "Natural Breaks." Change the number of classes to seven. Apply.

{__} To make the zero values show up clear, first double-click on the topmost areal symbol (next to the zero). Regardless of whatever pallet comes up, change to the Fill Pallet. Then assign the "clear" value by clicking on the clear square (upper left). Apply. A map should appear which shows a progression of colors based on the value of the "Cnty_unemp" field. The counties of other states should appear as clear.

{__} ***Change the background color to black:*** View ~ Properties ~ Select Color and pick Black.

If the map looks the way you want it, dismiss the legend editor.

If you want a real map, you can make a "Layout" in Arc View—complete with north arrow, border, scale bar, and so on. Besides this, Arc View has many, many more features and capabilities than have been shown here. This is beyond our scope here. Contact ESRI (www.esri.com) for information on Arc View.

Exercise 5–4: You can use the GPS track to evaluate the accuracy of the ArcUSA roads database.

{__} Dismiss the Cty2m attributes table. Zoom to the extent of the GPS track.

{__} Add the ArcUSA coverage RDS2M as a theme. (You will find it in the __:\GPS2GIS\LEX_KNOX\ARCUSA\ARCUSA_D\USA_2MG directory.) Edit the legend so it shows up in medium purple, with a linear symbol—one is available which even looks a bit like a road with a dividing median. Make it of width 3.

{__} ***With the Query Builder, select the records that relate to Interstate 75:*** Bring up the table for Rds2m. The "I-75" designation usually shows up in the table as a "75" in the field "Inter_rte1." But sometimes the same stretch of highway goes by

two different names. When I-75 is in common with another interstate highway designation, the "75" may appear in the table under the heading "Inter_rte2." To get all of I-75 you must include both column headings in your selection process. (Hint1: Use the "or" operator.) (Hint2: Or use "Add To Set.")

{__} Make sure that the distance units for the view are in kilometers. (View ~ Properties ~ Distance Units.)

{__} Zoom up and pan along the route to see how closely the GPS track corresponds to the selected segments of I-75, particularly in the Kentucky county just north of the Kentucky-Tennessee border. Measure the greatest distance from the GPS track to the interstate. It is _____ kilometers.

{__} Add the theme \GPS2GIS\LEX_KNOX\EXPORT \R090317A to the view. This is a GPS track based on fixes from a different receiver on the same trip as that which recorded I090317A. The GPS points from this second receiver were converted to an ArcInfo line coverage (rather than a shapefile). Make it a bright blue line of size 3.0. Ensure that I090317a.shp is painted on top of it.

Notice that the two GPS tracks seem to be almost congruent, whereas the representation of I-75 only roughly parallels them. Given the published accuracy of ArcUSA, a question which occurs is: Where is the interstate more than 1792 meters away from the GPS track? You can find this out by making the point-based GPS track active and then selecting those points of the GPS track which are within 1792 meters of I-75, which is the selected part of Rds2m.

{__} Make I090317a.shp the active theme. (Leave I-75 selected from the Rds2m database; it should still appear in yellow.) Pick "Select By Theme" from the "Theme" menu. You want to select the features of the active theme that **are within a distance of** 1.792 kilometers of the selected features of Rds2m. Make a new set of these features.

The dots that remain red are those which are not selected, and are therefore outside the 1792 meter average accuracy distance.

{__} Zoom to the I090317a.shp theme. Get the GPS track table. How many of the points were selected? _____. "Switch Selected"; how many are selected now? What percentage of the points were further away than the average accuracy? _____

This is not a completely fair assessment, however. At the end of trip the car departed from I-75 and took other roads. So, as a final task, you will **graphically select** those GPS fixes that were not taken on I–75.

{__} Switch the selected points so that the red dots indicate those fixes that are more than 1728 meters away. That is, the yellow dots show the selected fixes that are okay. You want to add to the selected set. Make sure I090317a.shp is the active theme. Make the view active. Zoom up on the southern end of the trip. Pick the "Select Feature" tool. Hold down the shift key (since you are adding to the selected set) and drag a box around the last set of red dots. When you release the mouse button those dots should turn yellow. Now the calculation of the percentage of points that were further away from the mapped version of the Interstate will be more accurate.

6
Integrating GPS Data with GIS Data

IN WHICH you learn approaches to converting GPS-software[1] data files to GIS-software data files,[2] practice with sampleGPS and digitized shapefiles and coverages, and thenundertake the process on your own.

OVERVIEW

Another Datum Lesson: I teach at the University of Kentucky's Department of Geography, in Lexington. Several years ago I borrowed a GPS receiver from Trimble Navigation to use in a class. It had occurred to me thatour departmental faculty directory listed names, office and home addresses,phone numbers, and so on, but not, as seemed appropriate for geographers,their geographic coordinates. So I sent my students out to park in my colleagues' driveways and collect GPS data, which we convened to an ArcInfocoverage based on World Geodetic System of 1984 (WGS84) Universal Transverse Mercator (UTM) coordinates.

We then digitized the major roads from Lexington-area U.S. GeologicalSurvey (USGS) 7.5 minute topographic quad maps based on the North American Datum of 1927 (NAD27). The maps indicated that to convert NAD27 toNAD83 (which is within centimeters of WGS84), one should move the gridlines 4 meters south and 6 meters west—hardly an issue for us, because ouraccuracy was limited by selective availability to perhaps 50 meters whencalculated over a number of measurements. It was, therefore, distressingwhen a graphic overlay of these two coverages put the current departmentalchair's house

smack in the median of Lexington's limited-access beltway.(He, in fact, lives a couple of football fields north of there.)

What I learned, the embarrassing way, was that while the area's latitude and longitude coordinates were adjusted by a few meters in the 1927-to-1983 datum change, the UTM coordinates were adjusted by more than200 meters in a north-south direction! So the statement on the map that thegridlines can be moved only a few meters was misleading—it referred onlyto the latitude and longitude grid lines. The UTM grid and the State Planegrid had much greater changes.

The moral of this story—which partly prompted the writing of this text-book—is that datum and coordinate issues can be tricky, and one must beespecially careful when combining data from different sources.

Reviewing What You Know

You have been given, or you have collected, files with the extensions SSF (Standard Storage Format) or COR (for differentially CORrected) files. These files have been processed and displayed using the Trimble Pathfinder Office software. Your goal now is to use these data files in a Geographic Information System (GIS) where they can be considered with many other data sources that you may have available. This is not a difficult process but you really must be careful: it is quite easy to get what looks like a reasonable GIS file, but one that has the locations wrong, thus making the activity worse than useless.

The key to converting from Trimble files to ESRI files is to know that you need only convert from SSF (or COR) files to what is called an ArcInfo **coverage** or to an Arc View **shapefile**. Once a coverage or shapefile has been obtained, the entire range of ESRI products is available for your use. It is also true that, no matter which Trimble products you use, ultimately you will have files in their standard file format. So it is as though you have a "data tunnel," with wide ranges of products on each side but with the

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[1] Trimble software, in particular.

[2] Environmental Systems Research Institute files, in particular.

restriction that the data must flow through a narrow passage (please see Figure 6–1).

The process of making an ESRI coverage begins with the Pathfinder Office software. This GPS software will generate a set of files. These files are not ESRI coverage files, but rather are files that ArcInfo commands will use to create the proper coverage. So you will be executing a multistep process. The result ultimately will be an ArcInfo coverage, which is a DOS, Windows, or UNIX directory (aka a folder) containing a number of files.

The process of making an Arc View shapefile is more direct. Pathfinder Office generates a shapefile file (actually, three or more
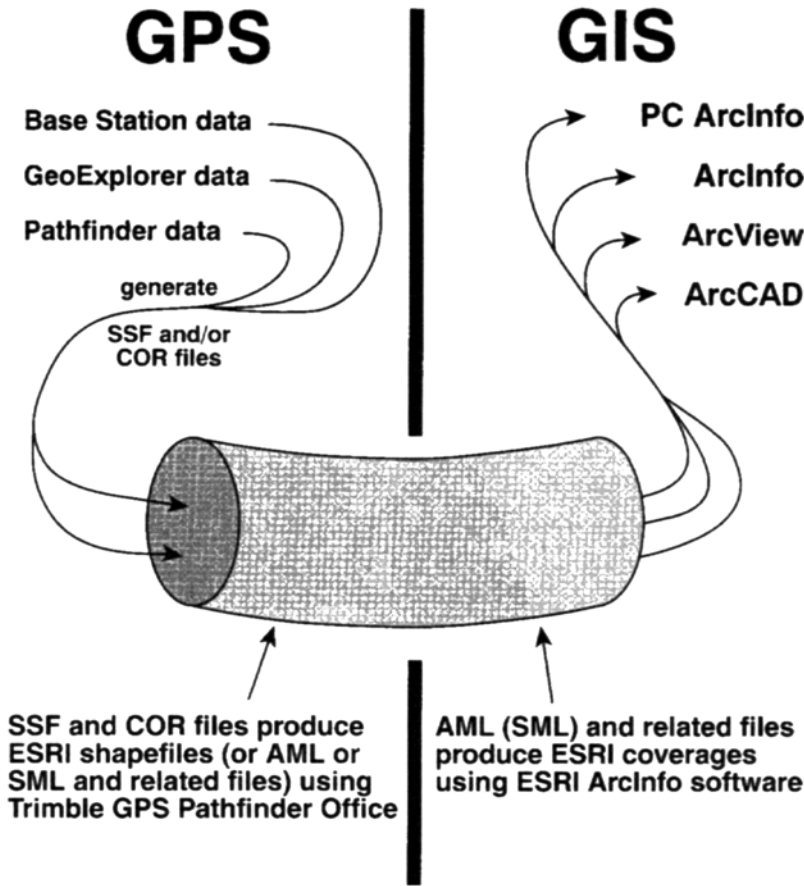
Figure 6–1. Data Tunnel: Trimble GPS data to ESRI products.

you will be executing a multistep process. The result ultimately will be an ArcInfo coverage, which is a DOS, Windows, or UNIX directory (aka a folder) containing a number of files.

The process of making an Arc View shapefile is more direct. Pathfinder Office generates a shapefile file (actually, three or more files in the same directory are needed to make an Arc View "shapefile") that are read directly by Arc View.

The reason to use a GIS with GPS data is to combine locational data from a variety of sources. So, first and foremost, you must ascertain the parameters of the existing ESRI coverages or shapefiles into which you wish to integrate the GPS data. If you get this wrong, everything will be wrong thenceforth. Among the things you must consider are:

- geodetic datum (and work in North America choices are usually NAD27, NAD83, WGS84)
- projection, if any, used to convert the data from latitude-longitude representation to a Cartesian coordinate system,
- units of linear measure, (e.g., meters, miles, survey feet, and many more), and
- units of angular measure (almost always degrees, but the issue of how fractional parts of a degree are represented can complicate things).

Prescription for Failure: Incorrect Parameters

Datum: As you perhaps proved to yourself in Chapter 1, there may be a significant difference in the UTM coordinates of a point represented in NAD27 and NAD83 (WGS84). In the United States, the values are different in the north-south direction about 200 meters, due primarily to humans learning more about the shape of their Earth. In the Western United States the east-west difference can be around 100 meters (e.g., Seattle area: 93 meters; San Diego area: 79 meters); it is usually less in the eastern part of the country (e.g., Bangor, ME area: 50 meters; Miami area: 17 meters; Lexington, KY area: 2 meters). You need to be concerned that you convert the GPS file to the datum used by any shapefile or coverage you wish to combine with the GPS data. You may

determine the datum of the coverage in a variety of ways. If your data are in ArcInfo coverage format there may be an ASCII "prj" (projection) file that describes the parameters of the dataset. If you are using shapefiles the information may be present as well; it would be found in a file with the extension "prj" appended to the name of the shapefile. A projection file contains information such as:

Projection	STATEPLANE
Zone	3976
Datum	NAD83
Zunits	NO
Units	FEET[3]
Spheroid	GRS1980
Xshift	0.00000000000
Yshift	0.00000000000
Parameters	

You should probably carefully investigate the sources of the data and their processing history so you can be certain of the datum and other projection parameters used.

Projection: As you will recall, the 2-D components of the Trimble SSF and COR files represent data in the latitude and longitude datum of WGS84, though they may be displayed in other forms. A fundamental dilemma of a spatial analyst is that the most accurate way to depict a point on the earth's surface is with latitude and longitude, but the numbers that represent such a point are in a coordinate system (spherical) that makes it harder to use these numbers in calculation for such quantities as distance and direction. Making these calculations in a projection is easier, but, of course, you get a (usually, slightly, if you are careful) wrong answer.

Further, maps that cover a lot of area that are shown in latitude-longitude are (usually) badly distorted visually, so most GIS users elect to store data in some projection in which the horizontal and vertical distances on the map correspond to the east-west and north-south distances on the Earth's surface. These maps appear (generally) much less distorted. However, there is now actual mathematical distortion for all but a few points. There is really no good solution to this dilemma; you must accept some inaccuracy.

What's vital, however, is that you tell the Trimble conversion process the correct projection to use so that the inaccuracies in your GPS data will be consistent with those in the other data your are working with. Arc View 3.x allows you to **display** data in another coordinate system besides the one in which it is recorded. Further, Arc View 3.2 contains routines which allow you to **convert** original data from one projection to another.

Linear Measurement Units: The choices are meters, feet (international), and survey feet. Survey feet formed the basis of the NAD27 datum[4]; international feet were used in NAD83 and WGS84. What's the difference? Not much, but enough to be significant in some situations. The differences come from a slight distortion of each English unit to make it conform to the metric system. An international foot is based on the idea that there are exactly 0.0254 meters in an inch. A survey foot is based on the equality of exactly 39.37 inches and a meter. If these two conversions were equivalent, you should get exactly the pure, unitless number one (1.0000000…) when you multiply them (0.0254 meters per inch times 39.37 inches per meter). They aren't and you won't. What is the product? Use a calculator. _____ The fractional part may look like an insignificant number, but it can mean a matter of several feet across a State Plane Coordinate zone.

Angular Measurement Format: Angular measurement units are important only if you are converting a file to a coverage which uses the lat-lon graticule directly. If you do use the graticule, you will want to select degrees, and decimal fractions thereof, because ESRI products don't directly utilize minutes and seconds as coordinate values.

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[3] ESRI software assumes that a "foot" is a "survey foot" but its projection engine can handle international feet. The difference is not insignificant over long distances. In 100 miles, for example, the difference is about a third of a meter—slightly more than a foot. Gunfire has been exchanged in disputes about property line positions differing by less than that. And the coordinate systems of many states span a few hundred miles.

The Old Conundrum: the "Spherical" Earth and the Flat Map

The GPS data in the receiver and in SSF files are stored in latitude, longitude, and height above ellipsoid coordinates. You can, of course, make ESRI shapefiles or coverages with latitude and longitude directly, as long as you select degrees and fractions of a degree as the output numbers, being sure to use enough decimal places. You may want to do this if you are going to combine the data with other coverages that are stored in that "projection." After all, this is the most fundamental, accurate way. You must realize, however, that any graphic representation of these data will be badly distorted, except near the equator where a degree of longitude covers approximately the same distance as a degree of latitude. Anywhere else, any image of the coverage is visually distorted, and the lengths of most lines is virtually meaningless, since the "length" is based on differences between latitude and longitude numbers. Such numbers do not provide a Cartesian two-dimensional space. (Recall the old riddle: where can you walk south one mile, east one mile, and north one mile, only to find yourself back at the starting point?[5] Not on any Cartesian x-y grid, for sure. Descartes, for his plane, insisted that a unit distance in the "x" direction be equivalent to a unit distance in the "y" direction.)

How to Use the Rest of This Chapter

The remainder of this Chapter is divided into two parts: Chapter 6a, which deals with using GPS files with Arc View, and Chapter 6b, which shows you how to use GPS files with ArcInfo. So at this point you should choose which software system you want to use (first?) and go to Chapter 6a or Chapter 6b.

For Arc View, Chapter 6a assumes you have version 3.2, but you can use most of the examples if you have only 3.1. This text does not cover Arc View 8.1, which is a subset of ArcInfo 8.1. If you are not adept at using Arc View 3.x, please go through Chapter 5 if you haven't already. The PROJECTS are best run if you have the Spatial Analyst and 3-D Analyst extensions to Arc View, but they are not vital.

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[4] State plane coordinate systems may also use survey feet.

For ArcInfo, the assumption is that you are working with Version 7 or Version 8 Workstation—**not** Version 8 Desktop. Version 8.1 is being released at the same time as this book. If you are using ArcInfo Version 8.1 Desktop you will have to make adjustments. The projects, examples, and exercises in Chapter 6b assume that you are conversant with ArcInfo.

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[5] At the North Pole. And at an infinite number of locations near the south pole, such that you could walk south one mile to a circle around the pole that has a circumference of exactly one mile (or one-half mile, or one-third mile, …).

6a
Integrating GPS Data with ArcView

OVERVIEW

The Conversion Process for ArcView[1]

The Trimble Pathfinder Office software generates ArcView shapefiles directly. While the process is somewhat simpler than that for creating coverages, all the caveats about being sure that datum, projection, coordinate system, and units are correct, apply equally.

A note on the shapefile data structure: ESRI refers to the Arc View-sty le representation of geographic data as a "shapefile." The shapefile is, in fact, a set of files which reside in the same directory. A shapefile named "abc," then, might consist of the files abc.shp, abc.shx, and abc.dbf. When you bring these files up in ArcView you see only abc.shp in the table of contents. You should realize, however, that all the files beginning with "abc" are involved. Using the operating system to copy or rename them is a bad idea. Use the ArcView capabilities (e.g., Manage Data Sources) to manipulate shapefiles. The shapefile arrangement is not quite as complex as the UNIX or NT ArcInfo arrangement but it can be confusing nonetheless.

After conversion you will find the files that constitute the shapefile in the Pathfinder Office Project Export directory.

The Files That Document the Export Process

The record of the conversion process is placed in two text files named something like exp1204a.txt (where 1204A indicates the month, day, and a sequence letter) and c111315a.inf. These files will also be in the Export directory.

```
Export Started...
Using Export Setup: AV_MDK#4
The following files in c:\gps2gis_ch6adata\river_av
will be exported:
     c111315a.cor

Reading file c111315a.cor

File c111315a.cor read successfully

1 input file(s) read.
83 position(s) read.
A total of 83 feature(s) read or created.

    83 point feature(s) created from GPS positions.
83 feature(s) exported.

3 output file(s) written to C:\Gps2gis_Ch6AData\
River_AV\export
    posnpnt.shp
    posnpnt.shx
    posnpnt.dbf

The file c111315a.inf contains information on the
settings used.

The file

c:\program files\common files\trimble\pfoffice\
config\expfiles.txt

contains a list of the files created.
```

The "exp" file will look something like this:

This file will give you a good idea of how the process went. This information is also available to you at the time the export process takes place; just ask to view the log of the export process. It is a good idea to at least look at the log when you do the export. Go back to the "exp" file if you run into any difficulty. (Note from the last lines that a third file is generated, buried deep in the general

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[1] The following section is for those who want to generate ArcView shapefiles. If you are only interested in ArcInfo coverages you should read Chapter 6b. You should be aware, however, that a good, less complicated way to get coverages is to generate ArcView shapefiles first and then convert them with the ArcInfo SHAPEARC command.

Pathfinder Office program files directory, that tells what files were generated—probably no new information there.)

The file that has the GPS file name (in this case c111315a.inf) contains information about the setup used. This file is certainly worth reviewing if the data are to be used for any important purpose. Probably the file should be reviewed by at least two people if the data are to be published or used by the public.

This information is descriptive of the process. Of course, your mail interest is in the shapefile that is generated by the Export process. The Step by-Step section that follows will lead you through the manufacture of a shapefile.

STEP-BY-STEP

Bringing GPS Data to ArcView GIS: Major Steps

A summary of the steps required to produce a GIS shapefile from Trimble Navigation GPS data is as follows:

1. Collect data with a GPS receiver.
2. Load data into a PC—in the process SSF files are created.
3. Examine data graphically in the PC, and correct it, differentially and otherwise, as appropriate.
4. Convert data from Trimble format to an ESRI ArcView shapefile using Pathfinder Office (or other third party software), being especially careful to use the proper parameters for datum, projection, coordinate system, and units.
5. In ArcView add each shapefile as a theme to a view, and rename it (or copy it, giving it a new name). Repeat the process for as many shapefiles as you have.
6. Obtain other GIS data such as coverages you digitize, TIGER files, GRIDs, TINs, DEMs, DRGs, soils or image files, available commercially or from governmental sources.
7. Use ArcView to integrate the converted GPS data with other GIS data.

PROJECT 6a-A

In November of 1993 the students and faculty of the Department of Geography at the University of Kentucky participated in a

```
Setup Used:              AV_MDK#4
Export Format:           ArcView Shapefile
Data Type:               Features
Not In Feature Positions: One point per Not in Feature
position
Export Notes:            No
Export Velocity Records: No
Export Sensor Records:   No
Export Menu Attribute As: Attribute Value
Generated Attributes:    GPS Time
                         GPS Height
Position Filter Details:
Filter By:               GPS Criteria
Maximum PDOP:            Any
Min Number of SVs:       3D (4 or more SVs)
Uncorrected:             No
P(Y) Code:               No
Differential:            Yes
Realtime Differential:   No
Phase Corrected(Float):  No
Phase Corrected(Fixed):  No
RTK Float:               No
RTK Fixed:               No
Non GPS:                 No
Coordinate System:       Universal Transverse Mercator
Coordinate Zone:         16 North
Datum:                   NAD 1927 (Conus)
Coordinate Units:        Meters
Altitude Units:          Meters
Altitude Reference:      MSL
Distance Units:          Meters
Area Units:              Square Meters
Precision Units:         Meters

Data Dictionary
---------------
Waypoint - Point Feature
   Label - String, Length = 100
```

cleanup of the Kentucky River. They took a GPS receiver on their trek; the antenna was mounted on the roof of a garbage scow (originally built as a houseboat). One file they collected along the river, from a marina to an "island" in the river, is C111315A.SSF.

```
    GPS Time - Time
    GPS Height - Numeric, DP = 3, Min = 0, Max = 0,
 Default = 0
 PosnPnt - Point Feature
    GPS Time - Time
    GPS Height - Numeric, DP = 3, Min = 0, Max = 0,
 Default = 0
 PosnLine - Line Feature
    GPS Time - Time
 PosnArea - Area Feature
    GPS Time - Time
```

Using postprocessing differential correction, it was converted to C111315A.COR. In this project you will make an ArcView point theme from the COR file, using the Trimble software and Arc View.

Make a Shapefile of a COR File

{__} Start Pathfinder Office in the usual way.

{__} In Pathfinder Office make a PROJECT named BOATTRIP_AV_yis (where yis represents your initials); set it up so that the associated folder is __:\GPS2GIS\RIVER_AV. Switch to that project.

{__} You should find a differentially corrected file C111315A.COR in your project's main folder. Open it in Pathfinder Office. Map it and Time Line it. The image you see should look something like a fishhook—in keeping with our nautical theme; the GPS track was taken over a period of about 45 minutes starting around 10:00 A.M.

{__} Under Pathfinder Office Options set the Distance Units to "US Survey Feet."[2] Make the other distance variables relate to Feet as well. The North Reference should be True.

{__} The Coordinate System should be selected by "Coordinate System and Zone." For the System use U.S. State Plane 1983. The Zone should be Kentucky North 1601. Measure altitude from mean sea level. Use the Defined Geoid. Make the Coordinate Units and Altitude Units U.S. Survey Feet.

{__} Don't change anything in Style of Display **unless** the Coordinate Order is **not** North/East or the Scale Format is **not** 1:X. The Time Zone should be Eastern Standard USA.

The process of making an Arc View theme from a COR file is complex enough, and error prone enough, that the Pathfinder Office software insists that you set the conversion up in advance.

You do this with an Export Setup file, to which you give a name. You may use this file for later exports— either exactly as it is or somewhat modified. There are seven major facets to the Export Setup file. In no particular order, they are:

• Data
• Output
• Attributes
• Units
• Position Filter
• Coordinate System
• Arc View Shapefile

{__} Bring up the Export window, by either picking Export under the Utilities menu item or by clicking on the Export icon on the Utilities toolbar. (See Figure 6–2.) In the window, under Input Files, Browse to find C111315A.COR in __:\GPS2GIS \RIVER_AV. Select it, then "Open" it.

{__} The next step is to pick a folder that will hold the exported shapefile. If you have set up the project correctly the default folder shown should be:

__:\GPS2GIS\RIVER_AV\EXPORT.

There are three sample export setups that work with ESRI products.

• Sample ArcInfo (NT & UNIX) Generate Setup
• Sample ArcInfo (PC) Generate Setup
• Sample Arc View Shapefile Setup

{__} From the drop-down menu under "Choose an Export Setup" find "Sample ArcView Shapefile Setup" and select it. Click "New" at the bottom of the window to bring up a "New Setup" window. (See Figure 6–3.) The idea here is to create a new setup that suits your needs, without changing the original setup. Choose "Copy of existing setup."

{__} Replace the text in the "Setup Name" window with AV_yis#1 to rename the new setup. Then OK the New Setup Window.

{__} A window should appear[3] entitled Export Setup Properties— AV_yis#1. The top portions should look like Figure 6–4. In this

---

[2] The "foot" in Arc View is the Survey Foot.
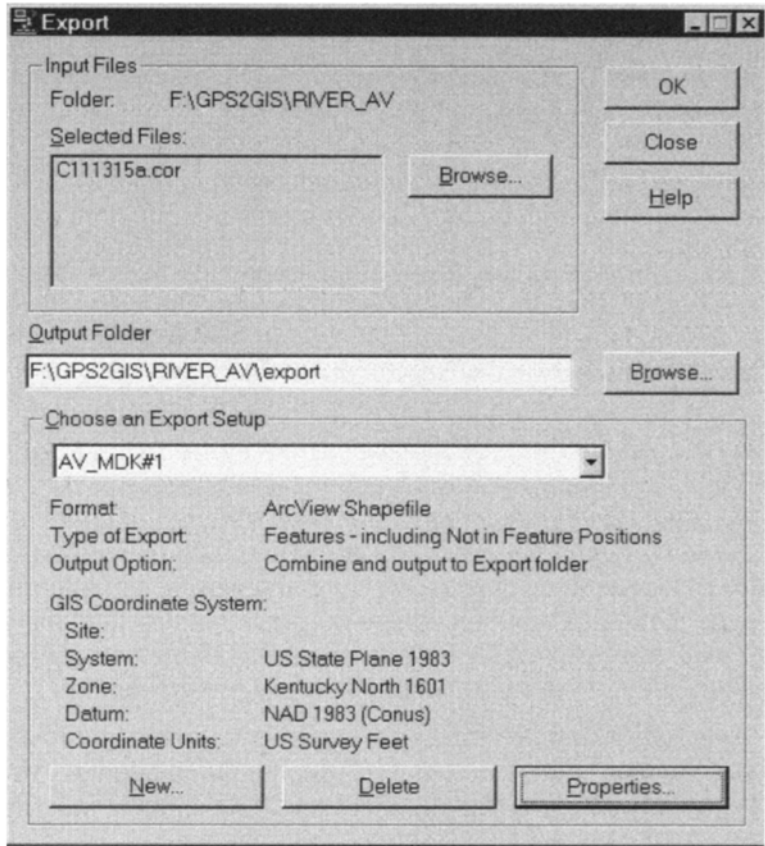
Figure 6–2. Exporting a GPS data file to a GIS format.

window are seven tabs, conforming to the list of seven facets listed above.

{__} Start with the Data tab. You want to export "Features—Positions and Attributes." Pick Export All Features from the drop-down list. You want to include Not-in-Feature Positions. And you want one point per Not-in-Feature position. See Figure 6–5.

{__} Under the "Output" tab, choose the option to combine all input files and place the results in the project export folder. (By default, Pathfinder Office will combine all of the input files into a single entity with a generic name such as "Posnpnt." If you want

---

[3] In the event that the setup already exists (perhaps because you have worked through this part of the text before), use the Properties button to bring up the window referred to here.
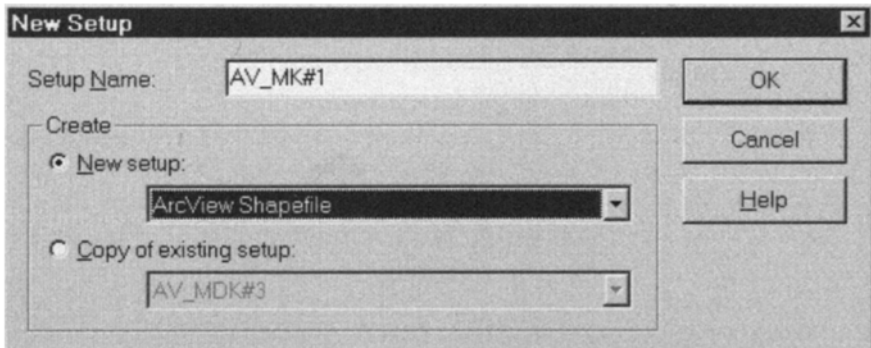
Figure 6–3. Creating a customized setup to make a shapefile.
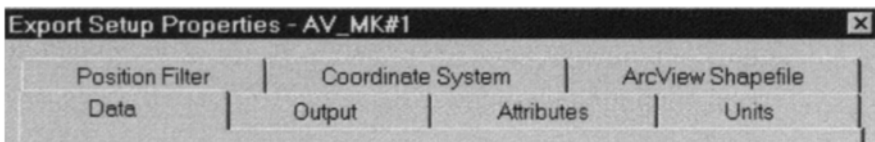
Figure 6–4. Set seven properties for a successful ArcView export.

the original name of a file to be carried through during the export process, or if you are exporting multiple files whose output you want to keep separate, you may choose the option "For each input file create output Subfolder(s) of the same name.") For the System File Format choose DOS files unless you are using some other system and the options are not grayed out.

{__} Under the Attributes tab, let's export a couple of attributes as well as positions.[4] Make checks by Time Recorded (under "All Feature Types") and Height (under "Point Features") as in Figure 6–6.

{__} The Units tab: Here you will tell Pathfinder Office to use the Current Display settings, which should be US Survey Feet, Square Feet, and Feet Per Second. Most of this window is "grayed out" because of other option choices you have made.

{__} Move to the Position Filter tab. Make the Minimum Satellites "4 or more," for good 3-D fixes. Accept any PDOP. Include only positions that are differentially corrected, i.e., "Differential." The result should look like Figure 6–7.

{__} Under Coordinate System, again use the current display coordinate system. Accept it after checking that it is U.S. State Plane, Kentucky North Zone 1601, NAD83 (Conus), coordinate units and altitude units in Survey Feet, and the Altitude reference as MSL. Plan to export only 2-D (XY) coordinates. If any of these
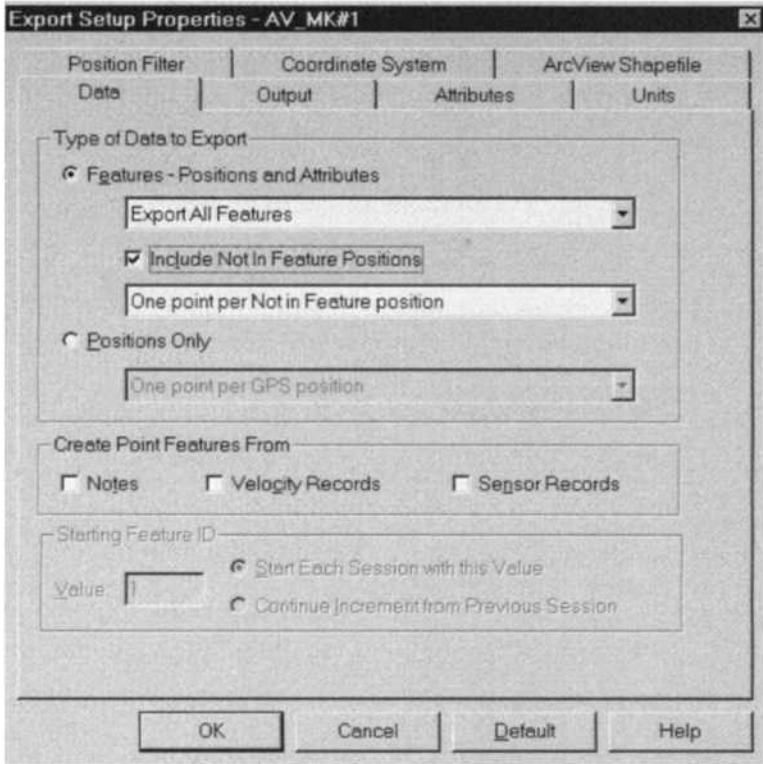
Figure 6–5. Defining the form of the data to be exported.

display settings aren't right, back out of Export and correct the settings under the main Options menu.

{__} Leave the options under "ArcView Shapefile" blank. Since you have now set all seven tabs, click OK to bring back the Export window.

{__} Review the Export window. It should look like Figure 6–2.[5] If not, click "Properties" and fix things.

{__} Click OK in the Export window. If you are asked about overwriting existing files, answer "Yes." You should then get an Export Completed window that looks like Figure 6–8. Click on More Details and read the resulting file. Dismiss that window and close its parent window.

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[4] At the time of this writing, due to an incompatibility between Pathfinder Office and Arc View, Trimble files exported to make shapefiles must contain at least one attribute or the Arc View software will not handle them correctly.
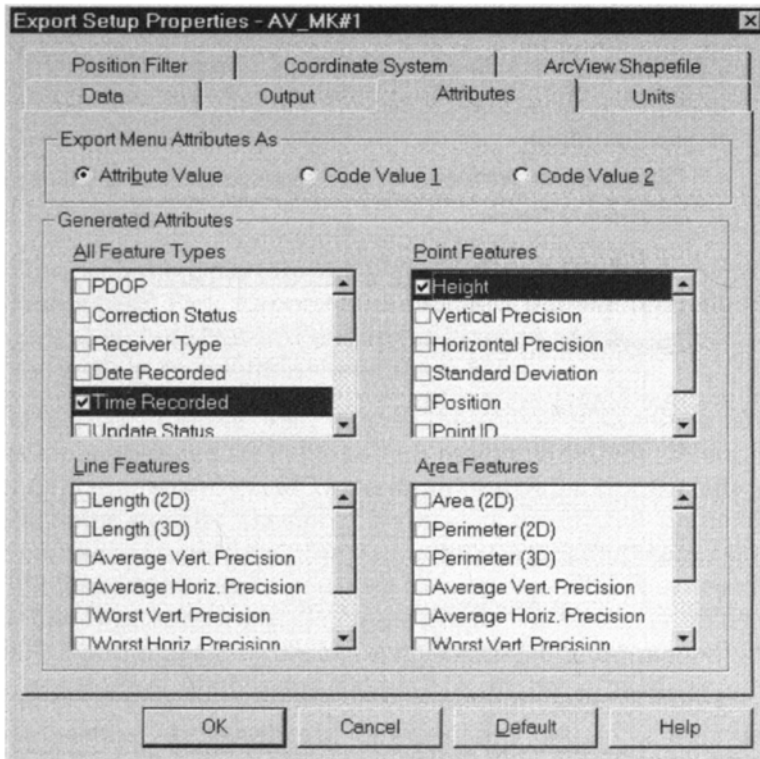
Figure 6–6. Defining the attributes to be exported.

{__} If you now look at the project toolbar of the Pathfinder Office window, where the project you are working on is named, you will see the amount of storage space left on the disk that contains that project. You will also see a file folder icon. Click on it and examine the project folder: __:\GPS2GIS\RIVER_AV. Now pounce on the Export folder. You should see files that constitute an ArcView theme as well as the information files generated during the exporting process.
C111315a.inf
exp1115a.txt (or some approximation thereof)

---

[5] This doesn't actually work in Pathfinder Office 2.70 running on Windows NT. The name you gave the Setup disappears from the field. However, if you continue the export will take place properly. You just can't save it. Users whose operating system is Windows 2000 will not have this problem. Go figure.
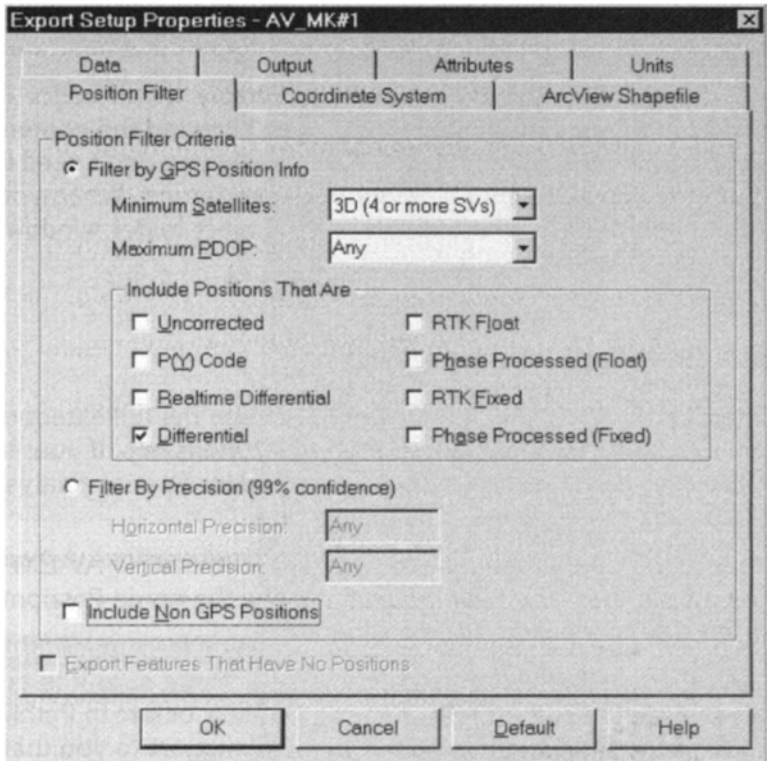
Figure 6–7. Determining the types of data to be exported.

    Posnpnt.dbf
    Posnpnt.shp
    Posnpnt.shx

If you don't see at least these files (perhaps with slightly different names), something went wrong and you will have to figure out what it was.

{__} If you pounce on a .txt or .inf file probably a text editor (e.g., Wordpad or Notepad in Windows) will open showing the contents of the file. Examine the .inf and .txt files. Normally you don't need these files but they can be helpful if something goes wrong. When you are sure that everything is okay, dismiss the project folder window and minimize the Pathfinder Office window.

See the Converted File in Arc View

{__} Start up ArcView. Make the window occupy the full extent of the screen. Create a new view. Under File click Extensions. If your
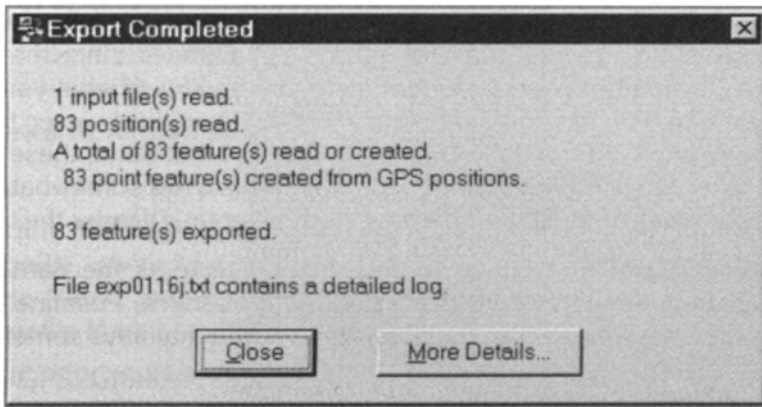
Figure 6–8. Results of a successful export process.

list of available extensions includes 3D Analyst and/or Spatial Analyst put checks beside those names. OK the window.

{__} Prepare to add a theme from __:\GPS2GIS\RIVER_AV \EXPORT where you put the GPS track. You should see the name Posnpnt.shp in the left side of the Add Theme window.

{__} Add the theme Posnpnt.shp. Turn it on. Make sure it is active. You should see the same GPS track that you saw before in Pathfinder Office. This (View1—see Figure 6–9) should suggest to you that you have indeed turned a GPS COR file into an ArcView shapefile.

{__} Look at the theme table: Attributes of Posnpnt.shp. (The first few records of the 83 records are shown in Figure 6–10. You should see there columns containing the time each fix was recorded and its height above mean sea level. Note the beginning and ending time for the data collection run. Note the wide variation of altitudes; since the river is very placid and almost level, this gives you an idea of what you can expect in the way of vertical accuracy for individual fixes—even those that have been differentially corrected. On the other hand, these data were taken a long time ago—things have improved somewhat. But the vertical will always be worse than the horizontal. Dismiss the table.

{__} Since Pathfinder Office (unfortunately) restricts the names of shapefiles generated by its export utility to Posnpnt, Posnline, and Posnpoly,[6] it is best to give the shapefile a name that says something about it. The easiest way to do this is to duplicate (that is, copy) the shapefile, giving the new file a name of your choice. This is how: make View1 active. Under File, click Manage Data
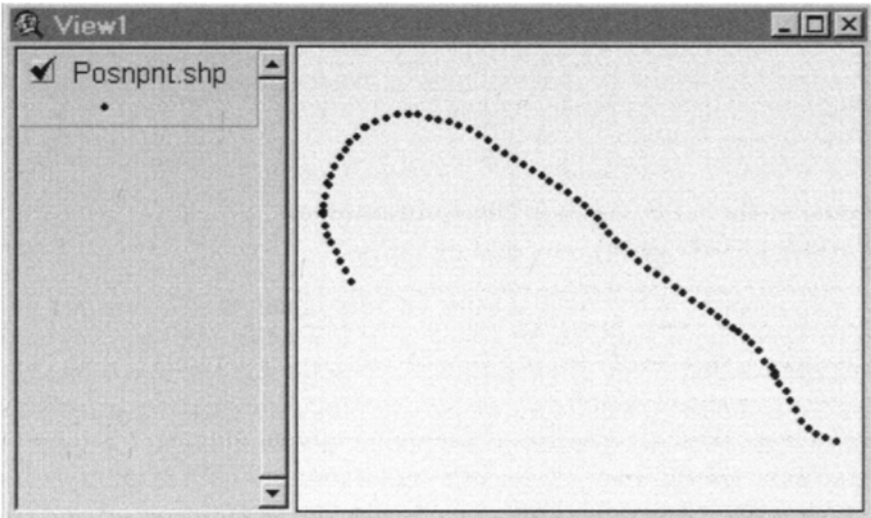
Figure 6–9. ArcView view of the Kentucky River GPS track.

Figure 6–10. ArcView table of the Kentucky River GPS track.

Sources. A Shapefile Manager window should come up showing the shapefiles in __:\GPS2GIS\RIVER_AV\EXPORT.

Click on Posnpnt.shp to highlight it and then push the Copy button. Type the new name, say Boat_sp83_yis.shp, into the "To Shapefile Name" blank and click OK. Cancel the Shapefile Manager Window.

---

[6] If you have multiple files to export you may have Pathfinder Office place each set of ArcView files into a separate directory whose name is the name of the SSF or COR file.

{__} Now add Boat_sp83_yis.shp as a new theme to the view. Make the plotting symbol a bright red dot of size six. (You may delete the Posnpnt.shp theme by making it the active theme, going into the Edit menu, and clicking Delete Themes.)

Look at the GPS Track in the Context of aVariety of GIS Data

The subject of this book is using GPS for input to GIS. Now that you have GPS data in Arc View let's look at it with other GIS data. We have available several digital maps and images of the relevant portion of the Kentucky River plus a couple of vector coverages of a few arcs from two USGS quadrangle maps. The county to the north is Fayette; that to the south is Madison. Of the two 7.5 minute quadrangles, the westernmost is COLETOWN; the other is FORD.

In the folder __:\GPS2GIS\RIVER exist the following:

- A line coverage digitized from the Ford, Kentucky quadrangle: FORD_VCTR
- A line coverage digitized from the Coletown, Kentucky quadrangle: COLE_VCTR
- A TIGER line file (shapefile) of the streams of Fayette County, Kentucky: FAY_TIGER
- A TIGER line file (shapefile) of the streams of Madison County, Kentucky: MAD_TIGER
- A digital raster graphics file scanned from the Coletown topographic quadrangle: COLE_DRG.TIF
- A small orthopohoto GeoTIFF image[7] (it is a digital orthophoto quadrangle that is 1/64th of a regular 7.5 minute USGS quad): COLE_DOQ64.TIF
- A Digital Elevation Model (DEM) in the form of an Arc/Info GRID consisting of "pillars of elevation" that are approximately 30 meters square: COLE_DEM
- A vector line coverage of the elevation contour lines generated from the DEM: COLE CONTOURS

---

[7] If regular TIFF files are used to portray geographic areas, a separate world file that provides the geographic coordinates of the TIFF must accompany them. GeoTIFFs contain the relevant world file; it is embedded. Trimble software does not recognize GeoTIFFs and hence requires the separate world file. Arc View may use either setup. You may convert a GeoTIFF to a TIFF and a world file with the ArcInfo command CONVERTIMAGE.

- A Triangulated Irregular Network (TIN) showing elevations derived from the DEM, in the form of an ArcInfo TIN: COLETIN
- A vector (polygon) coverage of most of the Coletown quadrangle showing soils: COLE_SOIL
- A vector polygon coverage of the Coletown geologic (surface rock) quadrangle: COLE_ROCK

In the steps below you will add these feature-based, grid-based, tin-based, and image-based themes.

{__} Enlarge the View1 window so it occupies most of the ArcView window, which should be set to occupy the full monitor screen.

{__} ***Add the feature-based themes from USGS 7.5 minute topographic quadrangles:*** First, note that all these themes are located in __:\GPS2GIS\ RIVER, not in RIVER_AV. The coverages FORD_VCTR and COLE_VCTR contain a few arcs digitized (without great accuracy) from the topo quads Ford and Coletown; the data have been converted to Kentucky State Plane coordinates in the NAD 1983 datum. In particular, an attempt was made to trace the banks of the Kentucky River and some local highways from the quad sheets. Add FORD_VCTR and COLE_VCTR as themes. Make the COLE_VCTR symbol a bright red line of size 1; use bright green for FORD_VCTR.

{__} Make Boat_sp83_yis the active theme. Zoom to Full Extent. Observe. Then Zoom to Active Theme(s).

You should see the GPS track, a few arcs outlining the river from the Coletown topo sheet, and a few arcs from the Ford topo sheet.[8] The starting point of the trip is in the southeast; at the other end of the track you can see the polygon outlining the island.

{__} Measure the length of the trip? (_____ feet).

{__} ***Change the viewing area and measure some other distances:*** Zoom up on the arcs around the island. What is the length of the island (_____ feet), and the width of the river near the island? (_____feet).

TIGER Line Files are a product of the U.S. Bureau of the Census. TIGER stands for Topologically Integrated Geographic Encoding and Referencing. TIGER files primarily contain street data—names, street numbers, census tracks, zip codes, county and state codes, and the geographic coordinates of these features. But they also include other types of data that can be represented in linear form, such as political boundaries, railroads, and streams.

FAY_TIGER and MAD_TIGER represent the streams of their respective counties.

{__} Display FAY_TIGER.SHP as a line theme using bright blue as a color and "2" as the size. Notice the two streams that come into the Kentucky River along the GPS track. Notice also that the north side of the river is considered a Fayette County stream.

{__} Display MAD_TIGER in the same fashion as FAY_TIGER but using a pale blue color.

{__} *Make a theme from the digital raster graphics (DRG) image ofthe Coletown quadrangle:* In the Add Theme window select Image Data Source from Data Source Types. Navigate to __: \GPS2GIS\ RIVER and add a theme named COLE_DRG.TIF. Pull its title in the table of contents to the bottom and turn it on. (From now on, put point-based themes at the top of the T/C, line-based themes below them, and image-based or grid-based themes at the bottom.) Observe. Zoom the view to full extent to see what a USSGS DRG image looks like. Then zoom up on the area of the GPS track.

{__} Look at the contour lines near the river. Obviously the elevation changes sharply, since the contour lines are close together.

{__} Further zoom up on the bend in the river. What is the NORMAL POOL ELEVATION? _____

{__} *Make a theme from the orthophoto "tif" file:* In the Add Theme window select Image Data Source from Data Source Types. Navigate to __:\GPS2GIS\RIVER and add a theme based on COLE_DOQ64.TIF. Drag its title to next to the bottom of the T/C (with only DRG theme below it) and turn it on. Zoom so the entire orthophoto image, plus the island, is in the view window. You can get an interesting perspective on the images by flipping COLE_DOQ64.TIF off and on. Experiment with different levels of magnification.

{__} *Make a theme from the digital elevation model (DEM) that isin the form of an ArcInfo GRID:*[9] In the Add Theme window select Grid Data Source from Data Source Types. From __: \GPS2GIS\RIVER add a theme based on COLE_DEM. Drag its title to the bottom of the T/C. Turn off the two image themes above

---

[8] Yes, this short trip crossed the boundary between two quad sheets. Not only are you learning about GPS and GIS, you are also confirming the First Law of Geography: any area of interest, of almost any size, will require multiple map sheets to represent.

it; turn it on and make it the active theme. Edit its legend so you can see nine or ten classifications of elevation: Legend Type-Graduated Color. Classification Field-Value. Color Ramp-Yellow monochromatic. Click "Classify" and choose "Natural Breaks."

{__} Notice the ranges of values of elevation. The lowest value in the area of the GPS track is, of course, on the surface of the river. Use the identify tool to see if the river elevation agrees with what you wrote before for the normal pool elevation. Again experiment with various levels of magnification, including full extent of the DEM.

{__} Redisplay the DRG, but keep the DEM the active theme. Use the Identify tool to check out the topo map elevations. Click on the topographic lines map where the text shows elevations of 600, 700, 850, and 900 feet near the bend in the river. Note the agreement (or lack thereof) between what the topo map says and the values of the underlying grid.

Another way of representing elevation on a map or in a GIS, with which you are familiar from your work with topographic maps, is through "iso-lines" or "contour" lines. All points on a given line represent the same elevation. The contour lines in the COLE_CONTOUR line coverage was developed by a computer program that processed the DEM for that quadrangle.

{__} Display the line theme COLE_CONTOUR, using a black line of width "1." Display this theme and the DRG theme only. With COLE_CONTOUR the active theme, use the identify tool to compare the elevation values of the black contour lines with those shown on the DRG. This process may work better if you zoom to a location away from the river, because the contour lines there are so dense that it is hard to see what is going on. You will notice that the contour lines from the two different data sets are close, but not congruent. Knowing the elevation at every point in an area is a tricky (actually impossible) task. These two data sets were derived in very different ways. They actually show a remarkable degree of agreement.

A TIN (Triangulated Irregular Network), along with contour lines, and digital elevation models, constitute a third way of

---

[9] In order to see this GRID you will need the Spatial Analyst extension or the 3-D Analyst extension. As indicated earlier, you may need to tell Arc View to install the extension(s) in the current session. To do this, go to the File menu and click Extensions. Put a check mark by Spatial Analyst or 3-D Analyst, or both.

representing topography in GISs. A TIN represents elevation by tessellating[10] the plane with triangles. Each triangle is positioned above the plane such that each of its three corners is at the proper elevation. The result, then, is a surface made up of flat triangular plates at different angles.

{__} ***Make a theme from the Triangulated Irregular Network ArcInfoTIN:***[11] In the Add Theme window select TIN Data Source from Data Source Types (you may have to scroll the drop-down list to see it). Navigate to __:\GPS2GIS\RIVER and add a theme based on COLE_TIN. Drag its title to the bottom of the T/C. Turn off any image themes above it; turn it on. Zoom up on the GPS track. Then zoom more to see the construction of the TIN. (If the surfaces of two or more triangles have the same slope you will not see the line separating them.) Again, with the DEM active, check out some elevations with the identify tool.

{__} Optionally, edit the legend of the TIN. It has its own legend editor, which you invoke by clicking on one of the colored rectangles in the T/C. Faces may show the Elevation Range (the default), the slopes of the triangles, or the aspect (direction they are inclined toward) of the triangles. You may also view the TIN from positions other than straight above. You could spend a full day exploring the different ways to display TINs. Come back to this if you are interested. Get your guidance from the ArcView Help files.

{__} ***Make a theme from an ArcInfo polygon soils coverage:*** In the Add Theme window select Feature Data Source from Data Source Types (you may have to scroll the drop-down list to see it). From __:\GPS2GIS\RIVER, add a theme based on COLE_SOIL. Drag its title to the bottom of the T/C and make sure it is the active theme. Turn off any image themes above it; turn it on. You will see arcs outlining the polygons but they will be all the same color. Double-click on the rectangular legend block in the T/C to bring up the Legend Editor. From the Legend Type pick "Unique Value" from the drop-down list and "Minor 1" from the Values Field. Use the "Bountiful Harvest" Color Scheme. Click Apply. Dismiss the Legend Editor. You should see 69 different values

---

[10] A 50-cent word that means "completely covering an area with geometric figures without gaps or overlaps." Actually, it is the projection of the triangles on the plane that tessellate it, since the sum of the areas of the triangles is more than the area of the plane—since the triangles are not parallel to the plane—but you get the idea.

represented in COLE_SOIL. In order not to have these all values cluttering up the T/C, click on "Hide/ Show Legend" in the Theme drop-down menu.

{__} Zoom up on the part of the GPS track that lies within the soils theme. Using the Identify tool, determine the Minor 1 classification of the soil type that predominates within the banks of the river. ____

{__} Just to get an idea of the character of the soils coverage for the entire quadrangle, zoom to full extent. The blank areas occur because soils data are not compiled primarily by quadrangle, but by county and quadrangle together.

{__} COLE_ROCK shows the surface geology classifications. Display it as a polygon theme in much the same manner as the soils coverage. Display it with unique values for each "Name" of each rock type. As you have seen with the other GIS data sets, it gets pretty interesting in the area of the river.

{__} Spend a few minutes looking at the various themes at different scales. One great advantage of a GIS is that you can make maps display what you want by turning various combinations of layers on and off. Play with that capability. When you have finished, determine if your instructor wants you to save the Project so he or she can see it later. If so, follow the directions given as to where to save it and what to call it. Close ArcView.

Of course, there is a long story behind each of the types of data that we have looked at briefly here. If you are interested in a particular type or source of data I suggest that you look first at the web for sources and then study web pages or texts for more detail.

PROJECT 6a-B

Blunders Caused by Using the Wrong Datum

One of the central difficulties in using GPS for input to GIS is mismatched parameters, as I have stated so often that you are sick of reading it. Indeed, the issue of getting the parameters of geographic data sets to match is a general problem with GIS. Let's look at what happens if we aren't careful.

{__} Bring up Pathfinder Office again. If you click on the icon for the Export Utility, the program will still be set to export the GPS

---

[11] In order to see this TIN you will need the 3-D Analyst extension.

file C111315a.COR to __:\GPS2GIS\RIVER_AV\EXPORT. However you want to export the GPS data in a different coordinate system, so click on New Setup. In the New Setup window choose "Copy of existing setup." In the "Setup Name" field replace "Copy of AV_yis#1" with "AV_yis#2." Click OK and up will come our seven-tab window.

{__} Make no changes in Data, Output, Attributes, ArcView Shapefile, or Position Filter (unless you were unable to save AV_yis#1, in which case you will have to set the parameters under those tabs to the values specified when you did the previous export). However we want to make this export setup so it makes a shapefile in the UTM coordinate system in the NAD27 datum. Also we want to set the export parameters specifically, rather than relying on the current display parameters. So, under the Coordinate System tab select (Use Export Coordinate System and then click on Change. Make the System Universal Transverse Mercator. The Zone should be 16 North, the Datum NAD27 (Conus), Coordinate Units Meters, Altitude Units Feet, and Altitude Reference MSL.

{__} Under the Units tab also use Export parameters. Use meters for all three options. Click OK in the Select Units window and then in the Export Setup Properties window.

{__} Double-check the Export window,[12] then click OK. You may be told that files will be overwritten. That's okay, since you copied the previously-made Posnpnt.shp to another name, thereby saving it. (Didn't you?)

{__} Start up ArcView and, with Manage Data Sources, copy the new Posnpnt.shp—it is in __:\GPS2GIS\RIVER_AV\EXPORT—to Boat_utm27_yis.shp.

{__} *In Pathfinder Office again export C111315a.COR for the thirdtime:* This time make an export setup named AV_yis#3 that makes a shapefile in the same UTM zone but uses WGS84 as the datum.

{__} Back in ArcView (you can switch back and forth between ArcView and Pathfinder Office simply by clicking the appropriate buttons on the Start bar or by using the Alt-Tab [or Alt-Shift-Tab combination], copy the new shapefile—giving it the name Boat_utm84_yis.shp.

{__} In ArcView, make a new view and enlarge its window. Add the following themes from feature data sources:
__:\GPS2GIS\RIVER_AV\EXPORT\Boat_utm27_yis.shp
__:\GPS2GIS\RIVER_AV\EXPORT\Boat_utm84_yis.shp

__:\GPS2GIS\RIVER\COLE_UTM
__:\GPS2GIS\RIVER\FORD_UTM

{__} Make a GPS track the active theme, and zoom to active themes. Notice the large difference in the two GPS tracks. Measure how much displaced (in meters) from each other they are in a north-south direction. _____ How much in an east-west direction? _____. Recall the results you got from the latitude and longitude worksheets in Chapter 1. You can use the Identify tool to determine which GPS arc is northernmost. Which is it?

{__} The banks of the river were digitized from topo quad sheets. In which datum would you say those sheets were developed? NAD27 or NAD83 (virtually the same as WGS84)? _____

PROJECT 6a-C

{__} ***Back in Pathfinder Office, generate the shapefile that is an arcrather than a sequence of points:*** Basically, you will repeat PROJECT 6a-A, using the Export Setup AV_yis# 1 except this time choose the " One line per group of Not in Feature Positions" option under the "Data" tab. Under the Attributes tab, select Length (2D) and Length (3D) as Line Feature attributes. When the export process is conducted for this Export Setup, the GPS fixes will generate a shapefile for an arc. Instead of PosnPnt.shp, you will get PosnLine.shp.

{__} Display PosnLine.shp with ArcView in a new view. Look at the theme table. First observe that it is very dull (only one record) compared with the (hardly exciting) table that showed each point. The time given is the starting time of the file. Also look at the two columns in the file labeled Gps_length and Gps_3dlength. Gps_length is the sum of the segment distances, in feet, of the GPS arc, considering only the horizontal components (two-dimensional) of the coordinate points. Gps_3dlength is the sum of the lengths of the sequence of lines that connect the three-dimensional coordinate points. You would expect it to be longer, but not that much longer, unless the Kentucky River was a major whitewater

---

[12] Unfortunately, if you are using Pathfinder Office 2.70 operating under Windows NT, the export setup field will have become blank. Continue. The export process will work as you have directed, but the Export Setup AV_yis#2 will not be saved. If you are using Pathfinder Office 2.51 or Windows 2000 this problem should not occur.

river. The large difference is due, actually, to the GPS errors in recording the heights of the points that make up the arc.

{__} Use Manage Data Sources to copy the PosnLine shapefile; make the new file name "KYARC_yis" where "yis" represents your initials.

Some points to consider: Suppose positions had been collected every 30 seconds on the boat trip, the positions were extremely accurate, and the boat stayed precisely in the middle of the river. Would the length of the two-dimensional arc, as found in the theme table, overstate or understate the length of the trip? _____. If there had been only small random errors in the GPS readings on this trip, what would be the effect of these on the length of the arc? _____. Do these two phenomena tend to reinforce or cancel each other? _____ .

PROJECT 6a-D

{__} In the __:\GPS2GIS\RIVER_AV directory find a GPS file named KYCLAUTO.COR. This is a track from the marina, north on an access road, north onto I–75 to Lexington's New Circle Road, and west on New Circle.

{__} Convert this GPS SSF file into an ArcView shapefile compatible with FORD_VCTR and COLE_VCTR coverages.

{__} Use ArcView to display this shapefile with FORD_VCTR and COLE_VCTR.

PROJECT 6a-E

{__} Either use the data you took while transporting the GPS receiver and antenna in Project 2A, or collect some new data. Find some GIS data that covers the same area in which you took the GPS data. Convert the GPS data with the appropriate parameters to an ArcView Shapefile and view it with other GIS data.

6b
Integrating GPS Data with ArcInfo

OVERVIEW

The Conversion Process for ArcInfo[1]

Once you have determined the parameters of the coverage you want to convert your GPS data to, you are ready to undertake the actual conversion process. In the Step-by-Step section, I will lead you through the process, but here I want to point out what the output of the process will be and what you will do with that output to get a coverage.

(A note on the coverage data structure: To review what you probably already know, ESRI refers to the ArcInfo style representation of geographic data as a **"coverage."** A UNIX or Windows NT ArcInfo coverage consists of a set of files, but some of the files are subsumed under a directory name that bears the name of the coverage and the rest are in an "info" directory. **Usingthe operating system to copy or rename them leads to disaster.** Use the ArcInfo commands (e.g., COPY, RENAME) to manipulate coverages.)

GPS data are, for our purposes here, primarily geographical points or fixes. (You can also include attribute data in some Trimble GPS files—we will do a bit of that here and look at it extensively in Chapter 7.) An ESRI coverage, as you know, can consist of:

- a set of individual points. Each point represents a 2-D location in some coordinate system (see Figure 6–11).
- a set of arcs. An arc is composed of a sequence of straight line segments. Each segment joins two adjacent (two-dimensional) geographic fixes. At each end of the arc is a geographic fix called
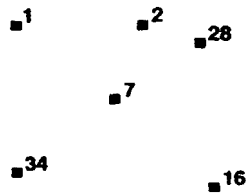
Figure 6–11. Graphics of an ESRI point coverage.
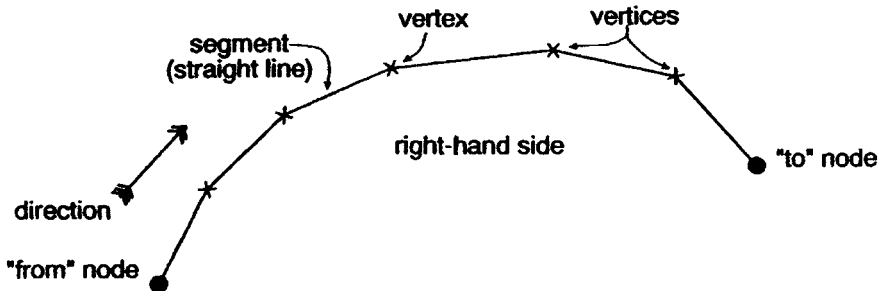
Figure 6–12. Graphics of an ESRI line (arc) coverage.

a node. All the other fixes, which determine the shape of the arc, are called vertices (see Figure 6–12).

• a set of polygons, which are closed figures made up of arcs (see Figure 6–13).

Each coverage may have a feature attribute table (or two) associated with it.

A GPS data file is simply a set of x-y-z locations, in sequence by the time at which they were recorded. So the GPS data contain the necessary numbers to allow you to make either a coverage which is a set of points, with a Point Attribute Table, or a coverage consisting of a set of arcs with an Arc Attribute Table (AAT). Of course, if you can make arcs you can make polygons.

The Trimble software also allows you to make the files that make polygon coverages directly, but I recommend against it, for a variety of reasons to be discussed later. If you want polygons, make the arcs as separate entities and then use ESRI tools such as ARCEDIT to put them together into polygons.

---

[1] The following section is for those who want to generate ArcInfo coverages. If you are only interested in Arc View shapefiles you should read Chapter 6a.
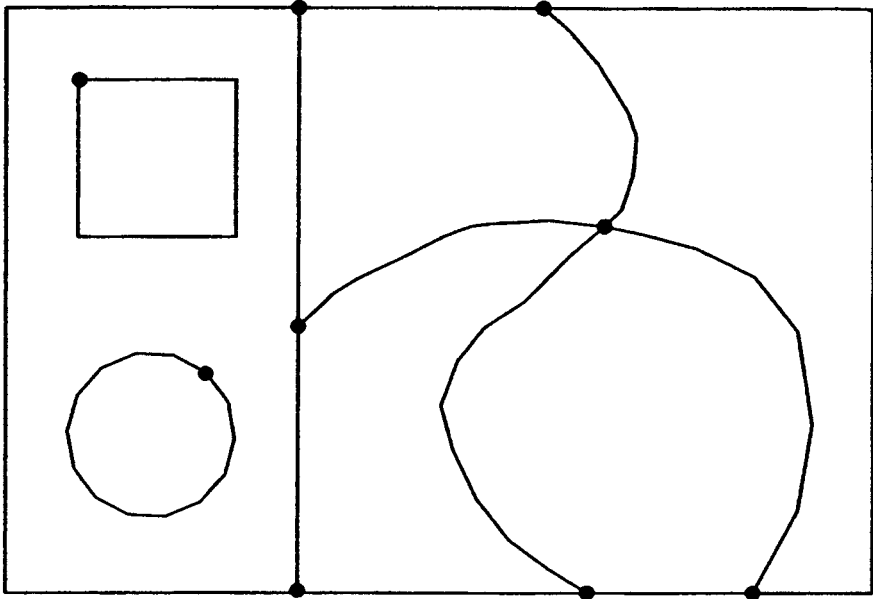
Figure 6–13. Graphics of an ESRI polygon coverage.

The Files That Generate Coverages

When you run the Trimble software with the "Arc Generate" option, several DOS[2] ASCII[3] text files are produced in the directory you specify. To recap, a DOS file identifier (file_id) is composed of a file name and an extension. The name may have eight characters, the extension three. This is sometimes called the DOS 8.3 format.[4] The file name for each of the files generated will be POSNPNT, POSNLINE, or POSNAREA depending on whether you choose to make points, lines, or areas. Extensions will perhaps be AML, PTS, PA, and so on.

This name will also be the name of the ESRI coverage which will ultimately be generated. For example, XO10203 A could be the name of the first GPS file taken on January second during the 3rd

---

[2] Disk Operating System. IBM DOS and Microsoft DOS were the predecessors of the current Microsoft Windows Operating System.

[3] American Standard Code for Information Interchange. A widely used, but hardly universal, set of bit patterns used to let one computer communicate with another without translation of the data. ASCII codes consist of eight bits, called a byte. For example, "R" is 01010010, "r" is 01110010, "3" (treated as a symbol, not a number) is 00110011, and "?" is 00111111.

```
GENERATE POSNPNT
INPUT POSNPNT.PTS
POINT
QUIT

BUILD POSNPNT POINT

&DATA ARC INFO
ARC
DEFINE POSNPNT.PA
POSNPNT-ID, 5, 5, I
GPS_TIME, 20, 20, C
GPS_HEIGHT, 8, 16, F, 3
```

UTC hour. Subsequent files produced by the Trimble GPS software would be X010203A.SSF and perhaps X010203A.COR. But when the Trimble GPS software is asked to export these files to make a point coverage it produces files with different file identifiers. These files all have the name POSNPNT,[5] but differ in their three-character extension. For example, if you specified that each fix in the SSF file was to become point feature in an ESRI coverage, the files you would expect to see produced would be:

POSNPNT.AML
POSNPNT.PTS
POSNPNT.PA
There will also be a file named
X010203A.INF
and one something like
EXP1123A.TXT

Yes, that does seem to be a lot of files, so some explanation is in order. POSNPNT.AML is the Arc Macro Language (AML) file that you will have ArcInfo execute to produce a coverage. It will look something like this:[6]

The file POSNPNT.PTS contains the x and y (or other positional) coordinates. The first few records will look something like this:

The file POSNPNT.PA contains attributes generated by the Trimble Export software, such as the time each point was taken and the GPS altitude of the point. Its first few records will look something like this:

---

[4] In UNIX and Windows NT a file name may be longer than eight characters.

```
 1, 2406882.000, 13766276.096
 2, 2406646.329, 13766337.098
 3, 2406404.095, 13766426.818
 4, 2406233.222, 13766537.956
 5, 2406051.469, 13766719.097
 6, 2405945.043, 13766942.767
 7, 2405824.723, 13767164.756
 8, 2405703.222, 13767361.683
 9, 2405567.580, 13767515.072
10, 2405443.123, 13767683.179
    1,10:04:07AM,583.657
    2,10:04:46AM,548.739
    3,10:05:14AM,553.189
    4,10:05:39AM,556.681
    5,10:06:08AM,593.653
    6,10:06:38AM,570.1
    7,10:07:09AM,586.364
    8,10:07:51AM,580.156
    9,10:08:41AM,544.13
    10,10:09:35AM,561.957
```

The Files That Document the Export Process

The record of the conversion activities are recorded in two text files named something like exp1123a.txt (where 1123A indicates the month, day, and a sequence letter) and c111315a.inf.

The "expxxxx.txt" file records the process that Export goes through and should be examined to assure yourself that things happened as they should. It will look something like this:

This file will give you a good idea of how the process went. This information is also available to you at the time the export process takes place; just ask to view the log of the export process. It is a good idea to at least look at the log when you do the export. Go back to the "exp" file if you run into any difficulty. (Note from the last lines that a third file is generated, buried deep in the general Pathfinder Office program files directory, that tells what files were generated—probably no new information there.)

The next file, the one that has the GPS file name (in this case c111315a.inf), contains information about the setup used. This file is cer tainly worth reviewing if the data are to be used for any important purpose. Probably the file should be reviewed by at least two people if the data are to be published or used by the public.

```
Export Started...
Using Export Setup: MK#01
The following files in
E:\GP2\New_GPS2GIS\New_stuff\GP2_Part5\RIVER will be
exported:
        C111315a.cor

Reading file C111315a.cor
File C111315a.cor read successfully

1 input file(s) read.
83 position(s) read.
A total of 83 feature(s) read or created.

        83 point feature(s) created from GPS positions.
83 feature(s) exported.
3 output file(s) written to E:\GP2\New_GPS2GIS\New_
    stuff\GP2_Part5\river\export

        posnpnt.aml
        posnpnt.pa
        posnpnt.pts

The file C111315a.inf contains information on the
settings used.

The file

c:\program files\common files\trimble\pfoffice\config\
    expfiles.txt

contains a list of the files created.
```

I show you these files for your edification only. In case something goes wrong you can look at them to debug the problem. Assuming you have set things up correctly, to produce the coverage POSNPNT all you have to do is get ArcInfo running and type:
　&RUN POSNPNT.AML
　and, presto, the coverage POSNPNT appears.[7]
　The AML file uses the two other files (the PTS file and the PA file) to produce the coverage. You'll explore this process in more detail when we go through the procedure step-by-step.

```
Setup Used:                  MK#01
Export Format:               ArcInfo Generate
Data Type:                   GPS Positions
Use of Positions:            One point per GPS position
Export Notes:                No
Export Velocity Records:     No
Export Sensor Records:       No
Starting ID:                 1
File Structure:              Windows
Export Menu Attribute As:    Attribute Value
Generated Attributes:        GPS Time
                             GPS Height

Position Filter Details:
Filter By:                   GPS Criteria
Maximum PDOP:                Any
Min Number of SVs:           3D (4 or more SVs)
Uncorrected:                 No
P(Y) Code:                   No
Differential:                Yes
Realtime Differential:       No
Phase Corrected(Float):      No
Phase Corrected(Fixed):      No
RTK Float:                   No
RTK Fixed:                   No
Non GPS:                     No
Include Altitude:            No
Distance Units:              Feet
Area Units:                  Square Feet
Precision Units:             Meters
Altitude DP:                 3
Distance DP:                 3
Area DP:                     3

Data Dictionary

---------------

Waypoint - Point Feature
   Label - String, Length = 100
   GPS Time - Time
```

STEP-BY-STEP

Bringing GPS Data to ArcInfo GIS: Major Steps

A summary of the steps required to produce an ArcInfo GIS

coverage from Trimble GPS data is as follows:

1. Collect data with GPS receiver.
2. Load data into a PC, making SSF files.
3. Examine data graphically in the PC, and correct it (differentially and otherwise), as appropriate.
4. Convert data from Trimble format to ESRI ArcInfo macro-language (AML or SML) files using Pathfinder Office, being especially careful to use the proper parameters for datum, projection, coordinate system, and units.
5. Execute the ESRI macro-language AML or SML file. (Another way to get a coverage is to use the TRIM2ARC.AML macro supplied by Trimble Navigation with the Pathfinder Office software. To use this software refer to the *GPS Pathfinder Office ExportUtility Software User Guide*.) Once a coverage is obtained, rename it using the ArcInfo RENAME command.
6. Obtain other GIS data such as coverages you digitize, TIGER files, GRIDs, TINs, DEMs, DRGs, soils, or image files, that are available commercially or from governmental sources.
7. Use ArcInfo to integrate converted GPS data with other GIS data using software modules such as ARCPLOT, Arc View, Overlay, andARCEDIT.

PROJECT 6b-A

In November of 1993 the students and faculty of the Department of Geography at the University of Kentucky participated in a cleanup of the Kentucky River. They took a GPS receiver on their trek; the antenna was mounted on the roof of a garbage scow (originally built as a houseboat). One file they collected along the river, from a marina to an "island" in the river, is C111315A.SSF. Using postprocessing differential correction, it was converted to C111315 A.COR. In this project you will make and display an ESRI point coverage from the COR file, using the Trimble software and ArcInfo.

{__} Start Pathfinder Office in the usual way.

{__} In Pathfinder Office make a PROJECT named BOATTRIPAIyis (where yis represents your initials); set it up so

---

[7] Actually, with some versions of Pathfinder Office you have to slightly edit the AML file. Details are given in the Step-by-Step section.

that the associated folder is __:\GPS2GIS\RIVER_AI. Switch to that project.

{__} You should find a differentially corrected file C111315A.COR in your project's main folder. Open C111315A.COR in Pathfinder Office. Map and timeline it.

{__} Under Pathfinder Office Options set the Distance Units to "US Survey Feet."[8] Make the other distance variables Feet as well. The North Reference should be True.

{__} The Coordinate System should be selected by Coordinate System and Zone. For the System use U.S. State Plane 1983. The Zone should be Kentucky North 1601. Measure altitude from mean sea level. Use the Defined Geoid. Make the Coordinate Units and the Altitude Units U.S. Survey Feet.

{__} Don't change anything in Style of Display **unless** the Coordinate Order is **not** North/East. The Time Zone should be Eastern Standard USA. The image you see should look something like a fishhook—in keeping with our nautical theme; the GPS track was taken over about 45 minutes starting around 10:00 A.M.

The process of making an ArcInfo coverage from a COR file is complex enough, and error-prone enough, that the Pathfinder Office software insists that you set the conversion up in advance. You do this with an Export Setup file, to which you give a name. You may use this file for later exports— either exactly as it is or somewhat modified. There are six major facets to the Export Setup file. In no particular order, they are:

- Data
- Output
- Attributes
- Units
- Position Filter
- Coordinate System

{__} Bring up the Export window, by either picking Export under the Utilities menu item or by clicking on the Export icon on the Utilities tool bar. In the window (see Figure 6–14) "Browse" to find C111315A.COR in __:\GPS2GIS\RIVER_Al. Select it, then "Open" it.

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[8] The "foot" in ArcInfo is the Survey Foot.

{__} The chore now is to pick a folder that will hold the exported coverage. If you've set up the project correctly the default folder shown should be __:\GPS2GIS\RIVER_Al\EXPORT.

{__} The next task is to choose a "Sample" export file from which you can tailor one that completely suits your needs.) **Don't modify theSample.**

There are three sample export setups that work with ESRI products.

• Sample ArcInfo (NT & UNIX) Generate Setup
• Sample ArcInfo (PC) Generate Setup
• Sample Arc View Shapefile Setup

If you are planning to use **either** a UNIX workstation version of ArcInfo or **ArcInfo running under Windows** NT **on a PC,** you want to choose the UNIX Setup. Only if you are running PC Arcinfo or ArcCad do you want the PC setup. (I discuss using the Arc View shapefile in Chapter 6a. By the way, Arc View can read coverages, such as the one we are about to make, so knowing how to make coverages allows you to form data acceptable to all ESRI products.)

{__} Choose either the "Sample ARC/INFO (UNIX) Generate Setup" or the "Sample ARC/INFO (PC) Generate Setup," as appropriate, from the drop down list. Then click "New." A window named New Setup will appear. (See Figure 6–15, which illustrates the UNIX or NT setup.) Choose "Copy of existing setup." A Setup Name such as "Copy of…" will appear in the text box. In that text box rename the setup to AI_yis# 1. OK the window.

{__} A window should appear[9] entitled Export Setup Properties—AI_yis#1. The top portions should look like Figure 6–16. In this window are six tabs, conforming to the list of six facets listed above.

{__} Start with the Data tab. You want to export "Features—Positions and Attributes." Pick Export All Features from the drop-down list. You want to include Not-in-Feature Positions. And you want one point per Not-in-Feature position. Make the Starting Feature ID 501 (this will become the first value of the cover-ID number); set it up so each session will begin with this value. See Figure 6–17.

{__} Under the "Output" tab, choose the option to combine all input files and place the results in the project export folder. (By default, Pathfinder Office will combine all of the input files into a
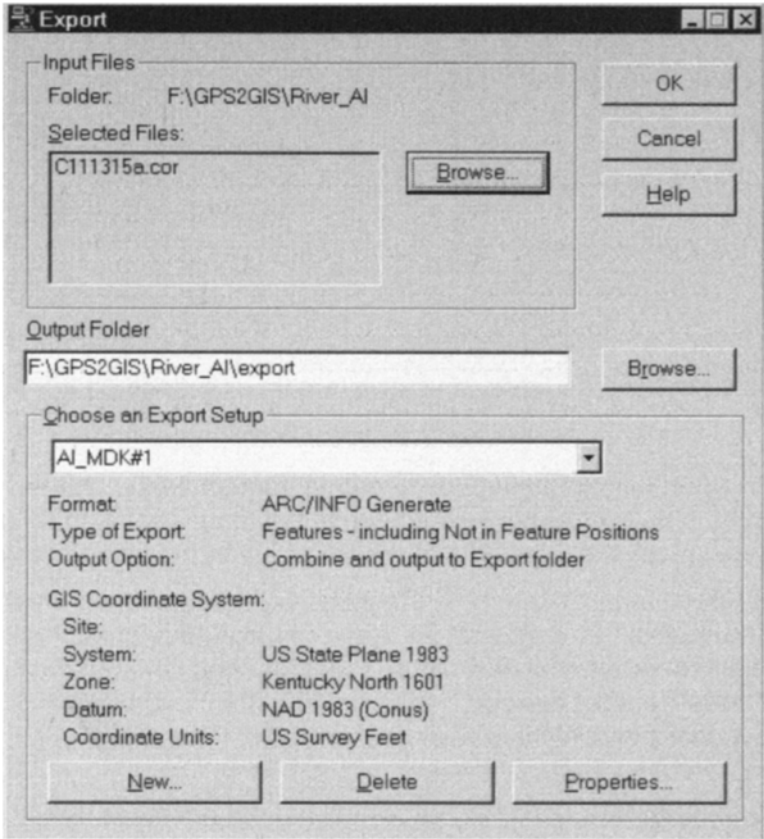
Figure 6–14. Exporting a GPS data file to a GIS format.

single entity with a generic name such as "Posnpnt." If you want the original name of a file to be carried through during the export process, or if you are exporting multiple files whose output you want to keep separate, you may choose the option "For each input file create output Subfolder(s) of the same name.") For the System File Format, pick UNIX Files for workstation ArcInfo, Windows Files for Windows NT ArcInfo, or DOS Files for PC ArcInfo, depending on where the output of the export process is headed.

{__} Under the Attributes tab, let's export a couple of attributes both to illustrate how it's done and so our Point Attribute Table (PAT) won't be so dull. Make checks by Time Recorded (under "All Feature Types") and Height (under "Point Features") as in Figure 6–18.
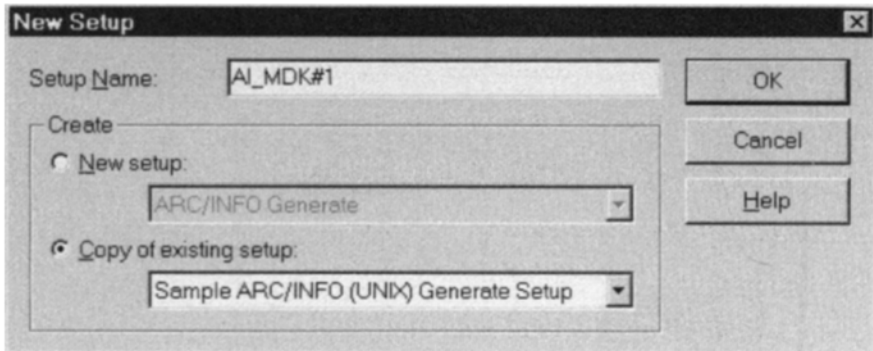
Figure 6–15. Creating a customized setup to make a coverage.
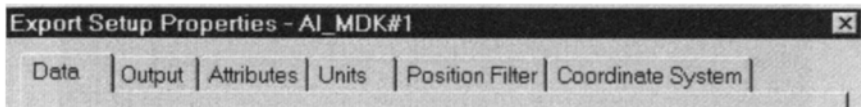
Figure 6–16. Set six properties for a successful ArcInfo export.

{__} The Units tab: Here you will tell Pathfinder Office to use the Current Display settings, which should be U.S. Survey Feet, Square Feet, and Feet Per Second. You won't be concerned with most of the other fields here because you aren't using Latitude and Longitude. So accept the default values.

{__} Move to the Position Filter tab. Make the Minimum Satellites "4 or more," for good 3-D fixes. Accept any PDOP. Include only positions that are differentially corrected, i.e., "Differential." The result should look like Figure 6–19.

{__} Under Coordinate System, use the current display coordinate system. Accept it after checking that it is U.S. State Plane 1983, Kentucky North Zone 1601, NAD 1983 (Conus), coordinate units in Survey Feet, with the altitude units in (International) Feet and that the Altitude reference is MSL. Plan to export only 2-D (XY) coordinates. If any of these display settings aren't right, back out of Export and correct the settings under the Options menu. Since you have now set all six tabs, click OK to bring back the Export window.

{__} Review the Export window. It should look like Figure 6–14.[10] If not, click "Properties" and fix things.

---

[9] In the event that the setup already exists (perhaps because you have worked through this part of the text before), use the Change Setup Options button to bring up the window referred to here.
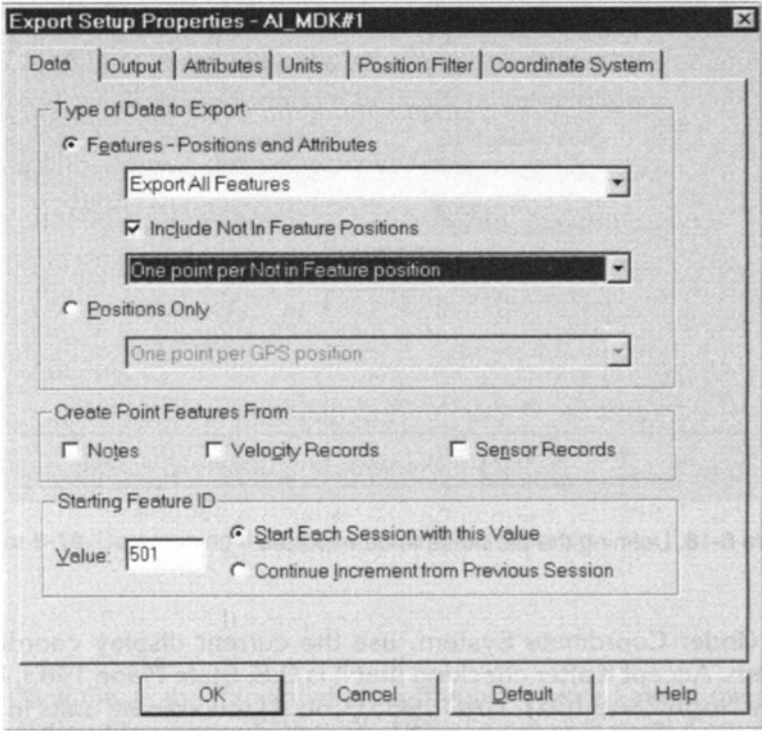
Figure 6–17. Defining the form of the data to be exported.

{__} Click OK in the Export window. If you are asked about overwriting existing files, answer "Yes." You should get an Export Completed window that looks like Figure 6–20. Click on More Details and read the resulting file. Dismiss that window and close its parent window.

{__} If you now look at the project toolbar of the Pathfinder Office window, where the project on which you are working is named, you will see the amount of storage space left on the disk that contains the project. You will also see a file folder icon. Click on it and examine the project folder: __:\GPS2GIS\RIVER_AI. Now pounce on the Export folder. You should see the files we discussed earlier—

---

[10] This doesn't actually work in Pathfinder Office 2.70 running Windows NT. The name you gave the Setup disappears from the field. However if you continue, the export will take place properly. You just can't save it. Users whose operating system is Windows 2000, or who are using an earlier or later version of Pathfinder Office, will not have this problem. Go figure.
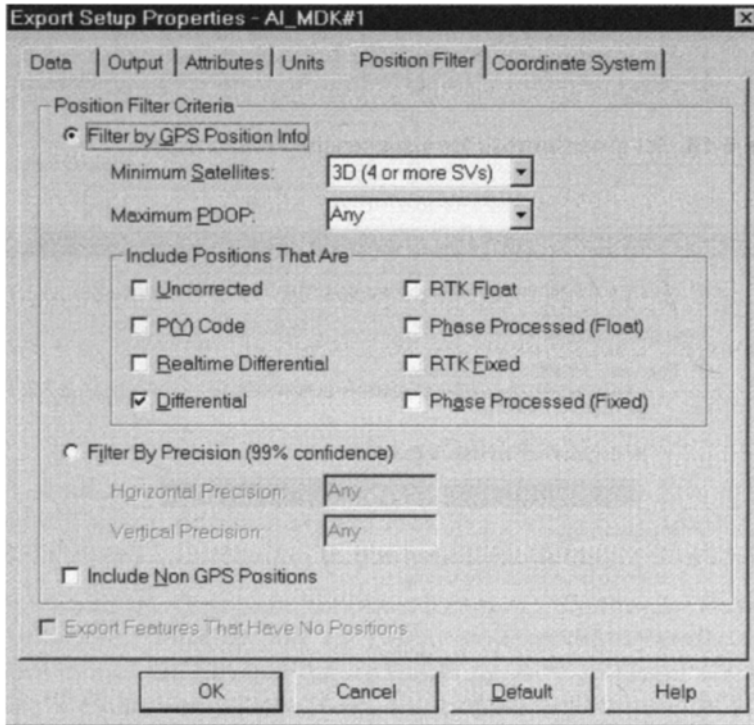
Figure 6–18. Defining the attributes to be exported.

POSNPNT.AML, and so on. If not, something went wrong and you have to figure out what it was.

{__} If you pounce on a .txt or .inf file a text editor (e.g., Wordpad or Notepad in Windows) will probably open showing the contents of the file. Examine the .inf and .txt files. Normally you don't need these files but they can be helpful if something goes wrong. When you are sure that everything is okay, dismiss the project folder window and minimize the Pathfinder Office window.

See the Converted File in ArcInfo

Start up ArcInfo. Don't forget to type &STATION 9999 or whatever it takes to set the display device and terminal. Using the WORKSPACE command, change to the directory

　　__:\GPS2GIS\RIVER_AI\EXPORT

An adjustment to the AML may be necessary to make it work properly. Modify the POSNPNT.AML in a text editor such as WordPad or NotePad as follows:
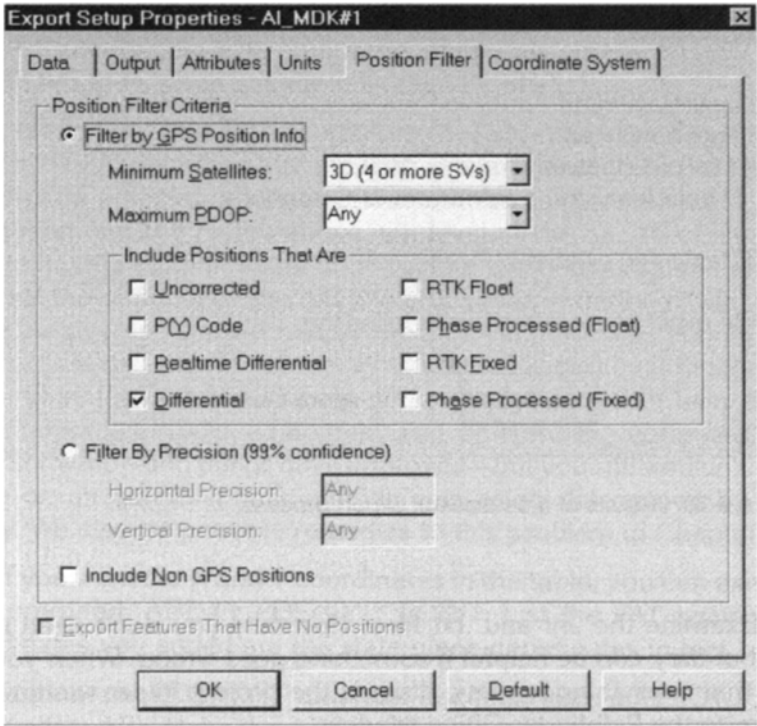
Figure 6–19. Determining the types of data to be exported.

Rewrite:
ADD FROM POSNPNT.PA
So it reads:
ADD FROM ..\POSNPNT.PA
Save the file and close the editor.

{__} Execute the AML by typing &RUN POSNPNT.AML. When it finishes you should be able to list the coverages (LC in NT or UNIX; LISTCOVS in PC) and see the coverage POSNPNT.

{__} *Now list the Point Attribute Table (PAT):* Type LIST POSNPNT.PAT. A portion of the table is shown in Figure 6–21. Here you should see the identifying items as well as the time each point was taken and the height above sea level of the fix. The first point should have a POSNPNT-ID of 501. Note the beginning and ending time for the data collection run. Note the wide variation of altitudes; since the river is very placid and almost level, this gives you an idea of what you can expect in the way of vertical accuracy for individual fixes—even those that have been differentially corrected. True, this is a file taken with older equipment and
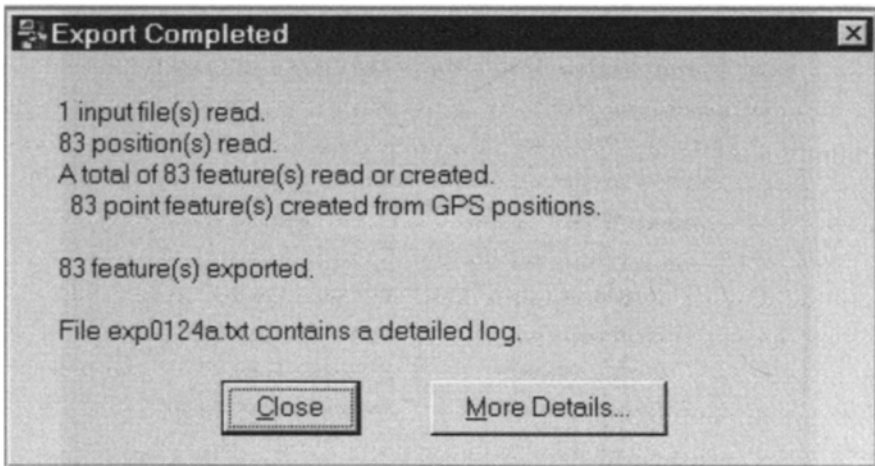
Figure 6–20. Results of a successful export process.

differentially corrected with older software—and things have improved—but you still wouldn't want to be on an airliner whose altitude was being determined by GPS solely. We discuss possible remedies to this problem in Chapter 8.

{__} If you want the X and Y coordinates in the table, you can execute the command: ADDXY POSNPNT POINT. List the PAT again. The coordinates you added are the state plane coordinates in feet.

{__} ***Look at the POSNPNT coverage itself:*** Go into ARCPLOT (command alias: AP). Make the ARCPLOT window fairly large. Type:[11]
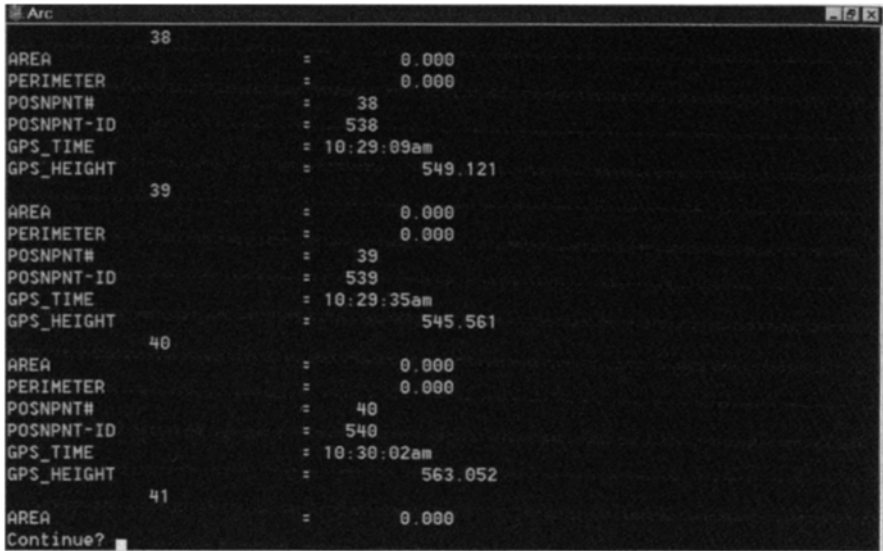
   MAPEXTENT POSNPNT
   TICS POSNPNT
   POINTS POSNPNT
   POINTTEXT POSNPNT POSNPNT-ID

{__} You should see the same GPS track that you saw before. Each point is numbered. Zoom up on the west end of the GPS track to see the identifying numbers clearly. (See Figure 6–22.) (Use MAPE *, make a box, CLEAR, and redo the POINTS and POINTTEXT commands above.) You should be satisfied that you have turned a GPS COR file into an ArcInfo point coverage of 83 points. Stay in ARCPLOT.

Figure 6–21. Point Attribute Table (PAT) from the export process.

Look at the GPS Track in the Context of a Variety of GIS Data

The subject of this book is using GPS for input to GIS. Now that you have GPS data in ArcInfo let's look at it with other GIS data. We have avail able several digital maps and images of a portion of the Kentucky River plus a couple of vector coverages of a few arcs from two USGS quadrangle maps. The county to the north is Fayette; that to the south is Madison. Of the two 7.5 minute quadrangles, the western one is COLETOWN; the other is FORD.

In the folder __:\GPS2GIS\RIVER exist the following:

- A line coverage digitized from the Ford, Kentucky quadrangle: FORD_VCTR
- A line coverage digitized from the Coletown, Kentucky quadrangle: COLE_VCTR
- A TIGER line file (shapefile) of the streams of Fayette County, Kentucky: FAY_TIGER
- A TIGER line file (shapefile) of the streams of Madison County, Kentucky: MAD_TIGER

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[11] You know this stuff, don't you? If not, you need some tutoring or reading in ArcInfo.
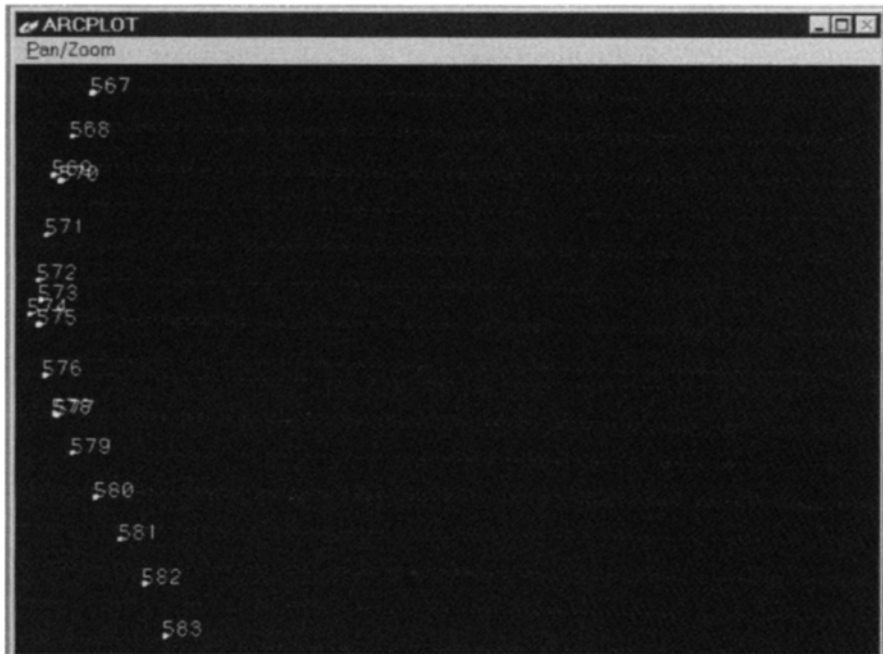
Figure 6–22. Portion of ArcInfo GPS track showing point IDs.

- A digital raster graphics file scanned from the Coletown topographic quadrangle: COLE_DRG.TIF
- A small orthopohoto GeoTIFF image[12] (it is a digital orthophoto quadrangle that is 1/64th of a regular 7.5 minute USGS quad): COLE_DOQ64.TIF
- A Digital Elevation Model (DEM) in the form of an Arc/Info GRID consisting of "pillars of elevation" that are approximately 30 meters square: COLE_DEM
- A vector line coverage of the elevation contour lines generated from the DEM: COLE_CONTOURS
- A Triangulated Irregular Network (TIN) showing elevations derived from the DEM, in the form of an ArcInfo TIN: COLE_TIN
- A vector (polygon) coverage of most of the Coletown quadrangle showing soils: COLE_SOIL
- A vector polygon coverage of the Coletown geologic (surface rock) quadrangle: COLE_ROCK
- An Arc Macro Language (AML) file named DKR. AML (Display Kentucky River) to display FORD_VCTR, COLE_VCTR, and the

```
/* File name: DKR.AML (for DISPLAYKYRIVER.AML)
/* AML displays GPS track and digitized quads
LINESYMBOL 3
ARCS FORD_VCTR
ARCS COLE_VCTR
ARCLINES FAY_TIGER_COV 8
ARCLINES MAD_TIGER_COV 8
POINTMARKERS ..\RIVER_AI\EXPORT\POSNPNT 38
```

GPS track. You may run this file after displaying other GIS data. It will cut down on the typing you do. (There is also a duplicate of this file named DISPLAYKYRIVER.AML.)

In the steps below you will add these feature-based, grid-based, tin-based, and image-based themes.

The AML file is there to prevent you from having to do a lot of typing. You may use it or modify it as you wish. It says:

{__} Study the AML carefully; understand what it will do when executed by ARCPLOT; we will use it shortly.

{__} CLEAR the ARCPLOT window. Set the mapextent to the GPS track, and change the workspace to __:\GPS2GIS\RIVER by typing the following

MAPEXTENT POSNPNT

ARC W __:\GPS2GIS\RIVER

{__} *Change the viewing area:* Rearrange the ArcInfo and ARCPLOT windows so that the graphic display area has the lion's share of the left side of the screen. Leave a piece of the Arc window over to the right so you can click on it when you want to type commands.

In the next steps you will use the AML to add data that have been converted to Kentucky State Plane coordinates in the NAD 1983 datum:

• the vector coverages based on two USGS 7.5 minute topographic quadrangles FORD_VCTR and COLE_VCTR, which contain a

---

[12] GeoTIFFs contain the relevant world file; if regular TIFF files are used to portray geographic areas a separate world file must accompany them. Trimble software does not recognize GeoTIFFs and hence requires the separate world file. Arc View may use either setup. You may convert a GeoTIFF to a TIFF and a world file with the ArcInfo command CONVERTIMAGE.

few arcs digitized (without great accuracy) from the topo quads Ford and Coletown (In particular, an attempt was made to trace the banks of the Kentucky River and some local highways from the quad sheets);
• the TIGER-based coverages depicting the streams in Fayette County and Madison County;
• the GPS track

{__} To see some of the vectors from the topo maps, the streams in the vicinity of the Kentucky River, and the GPS track type:
   &RUN   __:\GPS2GIS\RIVER\DISPLAYKYRIVER.AML   or, because you have set as the default the __:\GPS2GIS\RIVER workspace, because there is a duplicate file named DKR.AML, and because &R is a substitute for &RUN, you may type:
   &R DKR[13]
   You should see the GPS track in red plus a few arcs from the Coletown and Ford topo sheets (some of the arcs outline the river) in green and some blue arcs from the TIGER line stream files from Fayette County and Madison County. Each county treats the bank of the Kentucky River that is in its territory as a stream—so green and blue arcs are sometimes coincident and sometimes not, depending on the accuracy with which each was depicted. The starting point of the trip is in the southeast and you can see a green topographic line outlining the island at the other end of the trip.
   {__} *Use the ARCPLOT measure command:* You type MEASURE LENGTH and use the mouse cursor, clicking at the points along the path you want to measure. Follow the instructions in the Arc window. To complete the measurement and get the results, press the 9 key with the cursor in the ARCPLOT window; see the results in map units (survey feet) in the Arc window. Determine the length of the trip _____ feet, the length of the island: _____feet, and the width of the river near the island: _____ feet.
   {__} *Display the digital raster graphics (DRG) image of the Coletownquadrangle:*
   At the Arcplot prompt type:
   IMAGE COLE_DRG.TIF
   Run the AML again to put the vector data back on the screen. Click on the title bar of the ARCPLOT window to hide the Arc window. Then get the Arc window back.

{__} ***Further zoom up on the bend in the river:*** Type MAPE *. Then make the box so it includes the GPS track that shows in the DRG. CLEAR the window. Then redisplay the DRG and rerun the AML. What is the NORMAL POOL ELEVATION according to the DRG? _____

{__} ***Display the orthophoto file: COLE_DOQ64.TIF:*** Type:
IMAGE COLE_DOQ64.TIF
and redisplay the GPS track.

You can get an interesting perspective on the images by alternating between COLE_DRG and COLE_DOQ64.TIF. (Use the up and down arrow keys to alternately bring up the commands to generate the two IMAGES.)

{__} ***Display the digital elevation model that is in the form of anArcInfo GRID:*** COLE_DEM. A little wand waving is involved. If you don't understand the ARCPLOT commands don't worry about it. Type
SHADECOLORRAMP 1 5 BLUE GREEN
GRIDSHADES COLE_DEM VALUE EQUALAREA
Redisplay the GPS track and vector coverages.
Use the command ARCPLOT command
CELLVALUE COLE_DEM *
together with your mouse to find the elevations of various points on the GPS track. (The results are displayed as "VALUE" in the Arc window.) Do the answers appear to be at least roughly consistent with the Normal Pool Elevation you read from the DRG earlier? Check some of the surrounding elevations. Press "9" to end the CELLVALUE command.

{__} Redisplay the DRG. Using the CELLVALUE command again, check out the topo map elevations. Look at the topo map where the text shows elevations of 600, 700, and 900 feet near the bend in the river. You should see some agreement between what the topo map says and the values of the underlying grid.

{__} ***Display digitized contour lines of the Coletown Quadrangle:COLE_CONTOURS.*** The digital elevation model COLE_DEM was converted to an ArcInfo line coverage—another way to represent altitude. You can display the contour lines

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[13] Once you have typed this in as an ARCPLOT command you may (depending on the operating system), use the up and down arrow keys to redisplay the command so it may be reexecuted. You may find yourself wanting to do this in the course of the lesson.

around the river by selecting those whose "CONTOUR" value is between 550 and 700 feet:

    RESELECT COLE_CONTOURS LINE CONTOUR >550
    AND CONTOUR <700
    ARCS COLE_CONTOURS
    &R DKR

{__} ***Display the Triangulated Irregular Network ArcInfo TIN:COLE_TIN.*** The digital elevation model COLE_DEM was converted to an ArcInfo TIN—a third way to represent altitude. You can display the triangles of the TIN in numerous ways. Since we want to look primarily at the river we will show the triangles by slope, as the slope of the river should be close to zero and the area around it is quite steep. Type:

    CLEAR
    SHADESET COLOR.SHD
    TINSHADES COLE_TIN SLOPE
    &R DKR

The least slope category is shown by light beige and you can see the GPS track in the lightest areas. But the result is not too satisfying . To make real use of this sort of map you would need the legend.

Also look at the average elevations of the vertices of each triangle.

    CLEAR
    TINMARKERS COLE_TIN SPOT
    &R DKR

The lowest elevations are marked by white "+" symbols. Again, not too satisfying. But our point here is a quick demonstration of how GPS and GIS data can be matched up.

{__} ***Display an ArcInfo polygon soils coverage:*** COLE_SOIL, using the category "Minor1." Type:

    CLEAR
    POLYGONSHADES COLE_SOIL MINOR1.

Run the AML. The soil types are considerably different around the river.

{__} Look at the polygon attribute table:

    LIST COLE_SOIL.PAT.

{__} The Coletown geologic quadrangle has also been digitized. Its name is COLE_ROCK. After clearing the window, bring it up as well. Type:

    POLYGONSHADES COLE_ROCK NAME GQ_LUTBL followed by &R DKR. Because the river has cut down through the layers of

rock, the exposed surface shows rather dramatic changes over short distances.

{__} Spend a few minutes looking at the various coverages and images at different scales. This may not be too easy—and even if you can do it well, you can still appreciate why ESRI developed Arc View.

Of course, there is a long story behind each of the types of data that we have looked at briefly here. If you are interested in a particular type or source of data I suggest that you look first at the web for sources and then study web pages or texts for more detail.

{__} Then quit ARCPLOT

{__} Change the workspace back to

__:\GPS2GIS\RIVER_AI\EXPORT.

{__} Use the ArcInfo command RENAME to change the name of the coverage from POSNPNT to BOAT_SP83_yis.

RENAME POSNPNT BOAT_SP83_yis

{__} Minimize the ArcInfo Window.

PROJECT 6b-B

Blunders Caused by Using the Wrong Datum

One of the central difficulties in using GPS for input to GIS is mismatched parameters, as I have stated so often that you are sick of reading it. Indeed, the issue of getting the parameters of geo data sets to match is a general problem with GIS. Let's look at what happens if we aren't careful.

{__} Bring up Pathfinder Office again. If you click on the icon for the Export Utility, the program will still be set to export the GPS file C111315a.COR to __:\GPS2GIS\RIVER_AI\EXPORT. However we want to make some changes, so click on New Setup. In the Export Setup Name blank replace "Copy of AI_yis#1" with "AI_yis#2." Click OK and up will come our six-tab window.

{__} Make no changes in Data, Output, Attributes, or Position Filter. However we want to make this export setup so it makes a coverage in the UTM coordinate system in the NAD27 datum. Also we want to set the Export Parameters specifically, rather than relying on the current display parameters. So, under the Coordinate System tab select Use Export Coordinate System and then click on Change. Make the System Universal Transverse Mercator. The Zone should be 16 North, the Datum NAD 1927

(Conus), Coordinate Units Meters, Altitude Units Survey Feet, and Altitude Reference MSL.

{__} Under the Units tab also use Export Parameters. Use meters for all three options. Click OK.

{__} Double-check the Export window, then click OK. You may be told that files will be overwritten. That's okay, since you renamed the previously made coverage POSNPNT to another name, thereby preventing it from being involved in these new operations. A new set of AML files (which will generate a new coverage named POSNPNT) will be generated.

{__} With a text editor add the "..\" you needed before to make the AML work.

{__} Go back to ArcInfo (you can switch back and forth between ArcInfo and Pathfinder Office simply by clicking the appropriate buttons on the Start bar, or by using the Alt-Tab combination). Run the POSNPNT AML to make the new coverage. Then RENAME the new POSNPNT coverage that is in

__:\GPS2GIS\RIVER_AI\EXPORT, to BOAT_UTM27_yis.

{__} *In Pathfinder Office again, export C111315a.COR for the thirdtime:* This time make an export setup named AI_yis#3 that makes a shapefile in the same UTM zone but uses WGS 1984 as the datum.

{__} Fix the stupid AML.

{__} Back in ArcInfo, make the new coverage and rename it BOAT_UTM84_yis.

{__} In ArcInfo, display the following coverages:

Points   in   __:\GPS2GIS\RIVER_AI\EXPORT \BOAT_UTM84_yis

Arcs in __:\GPS2GIS\RIVER\COLE_UTM

Arcs in __:\GPS2GIS\RIVER\FORD_UTM

{__} Note that the boat is no longer in the river. Now add the points from

__:\GPS2GIS\RIVER_AI\EXPORT\BOAT_UTM27_yis

which is based on NAD27—the same coordinate system as the map from which the river was digitized. Observe the distance between the tracks. Note that the difference is much greater in the north-south direction than in the east-west direction. In this section of the country the UTM coordinates were moved about 200 meters along the meridians and almost not at all on the parallels when the new datum was calculated. Other sections of the United States will, of course, have different values.

{__} Zoom up on a portion of the GPS tracks. Measure how much displaced (in meters) equivalent points are from each other in a north-south direction. _____ How much in an east-west direction? _____. Recall the results you got from the latitude and longitude worksheets in Chapter 1.

{__} The banks of the river were digitized from topo quad sheets. In which datum would you say those sheets were developed?

This is another illustration that while the difference between NAD27 and WGS84 may be only a few meters based on latitude and longitude coordinates, it may be hundreds of meters different when based on UTM or state plane coordinates.

PROJECT 6b-C

{__} ***Back in Pathfinder Office, generate the files for a new coverage that is an arc rather than a sequence of points.*** Basically, you will repeat PROJECT 6b-A, using the Export Setup AI_yis#1 except this time choose the "One line per group of Not in Feature Positions" option under the Data tab. Under the Attributes tab select Length (2D) and Length (3D) as Line Feature attributes. The GPS fixes will generate files to make an ArcInfo line coverage rather than a point coverage. Those files will be POSNLINE.AML, POSNLINE.AA, and POSNLINE.GEN. The coverage name will be POSNLINE rather than POSNPNT.

{__} Run the POSNLINE AML (after fixing it with "..\") to produce the coverage. Display POSNLINE with ARCPLOT. Look at POSNLINE .AAT. First observe that arc attribute table is very dull (only one record) compared with the (hardly exciting) point attribute table that showed each point. The time given is the starting time of the file. Also look at the two fields in the file labeled Gps_length and Gps_3dlength. Gps_length is the sum of the distances, in feet, of the GPS arc segments, considering only the two-dimensional coordinates of each point. Gps_3dlength is the sum of the lengths of the sequence of lines that connect the three-dimensional coordinate points. You would expect it to be longer, but not that much longer, unless the Kentucky was a major whitewater river. The large difference is due, of course, to the GPS errors in recording the heights of the points that make up the arc.

Some points: Suppose positions had been collected every 30 seconds on the boat trip, the positions were extremely accurate, and the boat stayed precisely in the middle of the river. Would the length of the arc, as found in the AAT, overstate or understate the

length of the river centerline? _____. If there are small random errors in the GPS readings on this trip, what would be the effect of these on the A AT length of the arc? _____. Do these two phenomena tend to reinforce or cancel each other? _____.

When you execute an AML (or SML) file using a GEN file as input, a single arc will be created. This will be true, even if the arc crosses over itself. However, if you had such an arc which intersected itself, due to errors in the GPS recording process, and used BUILD with the LINE option, it would fail. If you CLEAN the coverage, you might get several arcs (and polygons). Without going into detail, let's simply say that you have to be careful when you translate GPS files into arcs. Examine the results carefully and be prepared to edit.

PROJECT 6b-D

{__} In the __:\GPS2GIS\RIVER folder find a GPS file named KYCLAUTO.COR. This is a track from the marina, north on an access road, north onto I–75 to Lexington's New Circle Road, and west on New Circle.

{__} Convert this file into an ArcInfo LINE coverage compatible with FORD_UTM and COLE_UTM.

{__} Graphically overlay this coverage with FORD_UTM and COLE UTM.

PROJECT 6b-E

{__} Now comes the real test! Can you integrate GPS data that you collected with GIS data that you digitize? In this project you might use the SSF file from PROJECT 2B, in which you moved the antenna through space. Whatever data you decide to use, you might want to plan to digitize the general area of the path on a USGS quadrangle.[14]

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[14] On the CD-ROM accompanying this textbook is text and a computer program that will help you digitize a USGS topo quad if you have no other efficient way to do it.

7
Beyond the Basics

IN WHICH you learn (a) how to collect attribute information aboutthe environment simultaneously with collecting GPS positiondata, (b) how to plan for important GPS missions, (c) aboutdifferential correction that takes place immediately, and(d) how to navigate using a GPS receiver.[1]

OVERVIEW

Attributes, GPS, and GIS

Overheard: Global Positioning System? A system for positioning theglobe?

Obtaining GIS Attribute Data withGPS Equipment and Software

From a software point of view, a GIS could be defined as the marriage of a graphic (or geographic) database (a GDB) with other databases—most frequently a relational database (RDB). These other databases—which contain **attribute** data about features in the GDB—are usually textual in nature, but sometimes consist of drawings, images or even sounds. (For example, you could key in, or click on, a street address to your GIS and be shown a photo of the house there.) The combination of a GDB and RDB allows the user to make textual queries and get graphical responses (e.g., show with a red "X" those streetlights which have not been serviced since August 1995) or, conversely, make a graphical query and get a response in text (e.g., indi cate the daily yield from

parking meters in this area that I have outlined on this image of the city using a mouse pointer).

If a GIS is a database with attribute information about geographical features, then it seems reasonable to collect the attribute data at the same time the positional data are collected. Thus far in this text we have not done this with GPS. The process of adding attribute data occurred after we generated the GIS coverages, since our GPS files contained only points in 3-D space. Suppose you collected a sequence of fixes along a two-lane road. Once the arc was depicted in the GIS, you would have to later add the "two-lane" fact to the record which related to the arc, if you wanted that information in the database.

Probably the most efficient and accurate way to use GPS to develop a GIS database is to collect the position data and the attribute data at the same time. Since a human operator is required to take the position data with a GPS receiver, it makes sense to have her or him enter the attribute data as well. Some GPS receivers, including the GeoExplorers, allow this sort of data collection.

The Organization of Attribute Data

The entry of attribute information into a GIS by using a GPS receiver is facilitated by a **data dictionary,** which is a hierarchical collection of textual terms stored in the GPS receiver's memory. The terms fall into three categories:

- Feature
- Attribute
- Value

"Feature" is used as it is in ArcInfo and Arc View. It refers to the feature-type that is the subject of a coverage or shapefile; it is the "Feature" of "Feature Attribute Table" such as an ArcInfo "PAT" (Point Attribute Table) or "AAT" (Arc Attribute Table). In Arc View, the parallel concept of Feature is the Theme. A feature-type becomes an ArcInfo coverage or an Arc View theme (made from a

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[1] The projects in this chapter are somewhat advanced exercises. At times you may need to have and use the manuals that come with the equipment and software. The instructions contained herein are more general than those given previously.

shapefile). Examples of feature-types are parking meters, paved roads, and land use. A point (or the average of a set of points) collected by the receiver for a given feature may become the basis for a record in a PAT or a record in an Arc View point-theme table. A sequence of points recorded along an arc may become the basis for a record in an AAT, or a record in an Arc View line-theme table.

"Attribute" is also a concept parallel to one in ArcInfo and Arc View. Attributes are the "items" or "columns" or "fields" of a table. Suppose, for example, you are developing a GIS database about parking meters. In addition to the positional data collected at the meters automatically, you might wish to be able to record each meter's identifying number as one attribute, and the condition of the meter as a second attribute. Information about the monthly revenue could be added later as a third attribute.

"Value" refers to the actual numeric or character entries in the table. Continuing our parking meter example, you would enter a meter number as the identifier of a particular parking meter and select a menu item "fair" to indicate the condition of the unit.

As you can see, there is a hierarchy to these terms: a feature contains attributes; attributes are columns of values.

Once you have collected feature data with a GPS receiver, if you are converting these data to ArcInfo coverages or Arc View themes, each feature-type[2] becomes a separate ArcInfo coverage or Arc View shapefile with its own feature attribute table. The table consists of the usual initial items (e.g., in ArcInfo: area, perimeter, internal, and user_ids for a PAT; from and to nodes, left and right polygons, length, interval, and user_ids for an AAT) plus columns for each attribute for which there are data. If a given feature (record) has a data value for a given attribute, that value becomes an entry in the feature attribute table or theme table.

The Data Dictionary

A data dictionary need not be long or complicated. For example, consider the following one, named Very_Simple. It contains only feature-types; it contains no attributes, so also no values.

Rocks (point)
Trees (point)

You could make this data dictionary on your PC using the Pathfinder Office software. Then you could transfer it to your GeoExplorer receiver.

To collect feature data with the Very_Simple data dictionary, you might begin a GPS file (for example, A010101 A), setting up the receiver to record a feature data point every 10 seconds. You might then move around the area of interest. When you arrived at a tree, you would select the feature "Tree" from the GeoExplorer menu and collect a number of fixes at, say, 10-second intervals. You would then close the feature and, perhaps, move to the site of another tree, opening the feature, collecting data, and closing the feature. Should you encounter a rock you could open the feature "Rock" and record fixes there. The fixes you record at each individual object are automatically averaged to produce a single point that approximates the position of the object.

Upon returning to your PC, you would use Pathfinder Office to transfer the file A010101 A, and generate POSNPTS.SSF.

Then you could use POSNPTS.SSF to generate the appropriate ESRI files. If you want Arc View shapefiles you can generate these directly with the Pathfinder Office Software. To get ArcInfo coverages the process is a bit more complicated, as you saw in Chapter 6b but easily do-able. Assuming you decide to make shapefiles, you would get three of them.

- POSNPTS.SHP
- ROCKS.SHP
- TREES.SHP

POSNPTS.SHP would consist of the points that the receiver recorded while you were walking between features.

ROCKS.SHP would contain a single point for each rock you visited. The point for a given rock would be the average of the fixes collected at that rock. That point would, therefore, provide approximate coordinates for that rock. A PAT would be formed with several records, one record for each rock. (The same idea would hold true for TREES.SHP.)

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[2] The word "feature" has at least two meanings. It can mean the subject of a coverage or shapefile (e.g., historical markers) or it can mean a particular entity (e.g., historical marker number 876). So I will use "feature-type" to indicate a general class of features, and "feature" to mean a particular entity.

Features with Attributes Attached

You might instead use a somewhat more complex data dictionary, Still_Simple, which might look something like this:

Rocks (point)
  Size (menu, no default value, required value)
      Small
      Medium
      Large

 Color (menu)
      Black
      Gray (default value)
      White
Trees (point)
 Size (numeric field, between 5 and 300, default value 10, two decimal places)
 Type (character field, maximum length 10)
Streets (line)
 Width (number of lanes, integer numeric field, min 1, max 10, default 2)
 Pavement (menu)
      Blacktop (default value)
      Concrete
      Other
      None
Intersections (point)
 T_intersection (menu, no default, required value)
      Yes
      No
Hydrants (point)
 Type (menu)
      Fire (default value)
      Lawn
Streetlights
 Bulb Type (menu)
      Incandescent
      Halogen
      Argon (default)
      Mercury

Assuming data were taken for all the feature types (Rocks, Trees, Streets, Intersections, Hydrants, and Streetlights) seven shapefiles coverages would result: POSNLINE.SHP, ROCKS.SHP, TREES.SHP, STREETS.SHP, and INTERSEC.SHP, HYDRANTS.SHP, and STREETLI.SHP. (Generated shapefile names will be a maximum of 8 characters long).

In addition to the standard items (columns, fields) in the shapefile table, ROCKS.SHP would contain the columns SIZE and COLOR. The values which could appear in these columns would be "Small," "Medium," and "Large," or no value at all for SIZE. What values could appear in the COLOR column? _____,_____,_____.

From the Environment, through GPS, to GIS

The process of recording attribute data with a GPS receiver is a good bit more complex than simply recording position data, which is itself, as you know only too well, not a trivial matter. To record attribute data you have to go through several steps:

- Build a Data Dictionary with a computer. This can be done on a PC using the Pathfinder Office software.
- Load the data dictionary file into the GeoExplorer. This process is similar to transferring position files and almanacs from the receiver to the PC; the data simply go the other direction. The PC may contain a number of data dictionaries; a GeoExplorer may store only one at a time. (A Geo3 may contain multiple data dictionaries.)
- Take the receiver to the field and open a file. Select a particular feature-type (for example, a point feature) from the menu. While the unit is automatically collecting position information, you manually select the appropriate attribute and value items. When enough fixes have been collected, stop the data collection process for that feature (i.e., close the feature). If the feature-type is of the "point" type, the fixes obtained will be averaged so that a single point represents the given point feature.
- Continue to collect data in the field. The data collected when no feature is selected may ultimately become one ArcInfo coverage or Arc View shapefile. For each feature-type for which you collect data, a coverage or shapefile may be built. That coverage or shapefile will contain the number of individual features for which you recorded position information. Note that a given data

collection session could result in a number of Arc View shapefiles (or ArcInfo coverages), the data for which might all be contained within one GPS file. Linear features may be collected in a somewhat similar way.

- Close the GPS file. Open a new one if you like and collect additional feature data, or simply positional data, as you wish.
- Return to your office or lab and upload the files from your GPS receiver to the PC in the usual way.
- Differentially correct the files.
- Using Pathfinder Office, produce Arc View shapefiles, which will become themes, or produce the SMLs (for PC ArcInfo) or AMLs (for workstation or UNIX ArcInfo) and associated ESRI files that, when executed, will produce ArcInfo coverages.

To practice seeing and using the feature attribute collection abilities of GPS, do PROJECTS 7A, 7B, 7C, and 7D.

STEP-BY-STEP

Attributes, GPS, and GIS

PROJECT 7A

Demonstrating Feature Attribute Data

In March of 1999 on different occasions, a light plane was flown from Lexington to surrounding airports recording GPS position and feature data. Usually a "touch and go" (brief landing and takeoff) was accomplished in which the aircraft wheels contacted the runway and a GPS fix (including the GPS altitude and local time) was recorded in the GPS receiver. Feature data, including the altitude reading from the aircraft altimeter and the published altitude of the airport, was likewise input. You will examine one of these flights: a trip from Bluegrass Airport near Lexington, Kentucky to the Mont-gomery County Airport near Mount Sterling, Kentucky. On this particular flight a full-stop landing was done at the destination airport. The datalogging was done with a Trimble Aspen PCMCIA card (with required external antenna) in a laptop computer, rather than a GeoExplorer.

The Aspen system has several advantages over simply using a self-contained receiver-datalogger. For one, you have a full
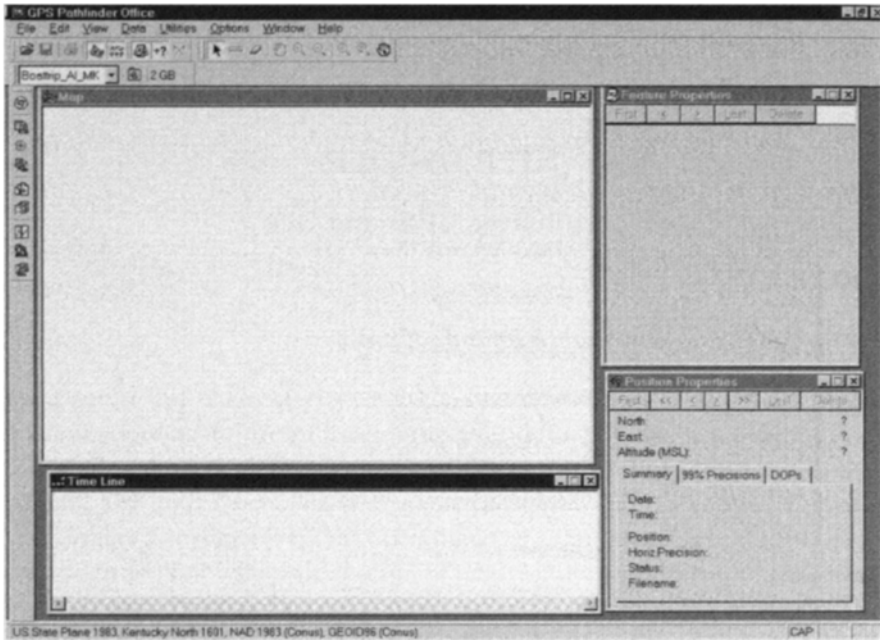
Figure 7–1. Screen layout of map, time line, position, and feature windows.

keyboard with which to enter data. Further, you have a screen with which you can display a map of the area and see your locations and progress in context. On the other hand, the laptop is less rugged and uses more power than a GeoExplorer, and some laptop screens are difficult to read in bright sunlight. The cost of Aspen software and PC card is less than a GeoExplorer. When you add the cost of the laptop, the total cost is more. But you may already have the laptop computer. As you can see, there are many considerations involved in what GPS datalogging system you should use for particular applications.

{__} In Pathfinder Office set up the following parameters: Kentucky state plane coordinates, north zone, NAD83; survey feet for all linear measurements; time zone EST; altitude MSL.

{__} Open up the Map, Time Line, Position Properties, and Feature Properties windows. Make the Map window occupy most of the upper part of the left two-thirds of the screen and arrange the other windows as shown in Figure 7–1.

{__} In the folder ___:\GPS2GIS\Flying_Tour, open the file R032720A.COR and the background geotiff files LEX.TIF and

MTS.TIF. Represent Not In Feature data with medium red dots. Zoom to Extents.

{__} Zoom up the westernmost image so that it fills the Map window. You should see most of Bluegrass Airport, including the northeast end (the departure end) of runway 4. (See Figure 7–2.) The GPS track was started just after takeoff. Using Position Properties, determine the altitude of the plane at the first GPS fix. _____. The published airport elevation is 979 feet.

Airport runways are designated by taking their approximate magnetic heading (to the nearest 10°) and dropping the final zero. So aircraft taking off or landing on runway 4 head approximately 40°, that is, almost directly northeast.

{__} Zoom up on the northeast end of the runway. You can see numbers painted on the concrete. Aircraft landing toward or taking off to the southwest would refer to this runway as "two-two"; 220° is the reciprocal of 40°. Use Zoom to Previous so that the entire airport image fills the map window

{__} In View ~ Layers ~ Features you will notice feature names of Altitude and Airport. Represent "Altitude" with a blue dot and "Airport" with a green dot. Pathfinder Office is aware that the Altitude and Airport layers exist because you have opened a file that contains those feature-types. Represent "Not In Feature" data as fat red dots.

{__} Make the Map window active by clicking on its title bar. Turn on Auto-pan to Selection. Using the position properties window, push "First" and then begin moving along the GPS track with the ">" button (or Alt-> key combination). Note the aircraft's altitudes during the climb-out phase of the flight. At point 14 or 15, stop and examine the track. You should see a blue dot to the east of the selected fix.

The blue dot represents a **quickmark**—a point feature that is made while moving along a path. A quickmark's position consists of an interpolation between the two fixes that bound it, in terms of time, one before and one after. Normally, as you will see later, a point feature's position is made up of the average of a number of fixes that are collected at the same spot. You can't do this while whizzing past a point of interest at 100 miles per hour, so some GPS equipment, such as the Aspen PCMCIA card with a laptop computer, allows you to collect quickmarks. A quickmark identifies a position and the operator can put in the attribute information later. (With other GPS equipment without the quickmark feature

Figure 7–2. GPS track departing Bluegrass Airport.

you simply have to take a point feature consisting of a single point at the right moment.)

{__} Continue moving along the GPS track. After fix 16, "Not in Feature: 16" will change to "Position: Quickmark." In the Feature Properties window you will see "MSL 0" and "Barometer 29.92."[3] These are default values for the point feature; that is, the operator

triggered the quickmark that recorded the position but didn't enter any feature values.

{__} Continue along the GPS track. Notice that the counting of Not in Feature fixes has restarted at 1. There are only three such fixes before the next quickmark point feature. Move ahead to that point feature. Here the operator recorded that the aircraft altitude (MSL) was 2,800 feet, according to the altimeter, which was set at 30.18—the value that the ground controllers had transmitted to the pilot before takeoff. What was the GPS altitude? _____

{__} Continue along the GPS track with the ">" button. You may note that there are some 60-plus fixes remaining and that the scenery has become very dull. We can speed things up. Make the Feature Properties window active by clicking on its title bar. If you pause the pointer over the ">" button **in that window** you will see that it will take you to the next feature. Click that button.

{__} You should see a DOQ of the airport near Mount Sterling. Just as the plane landed a quickmark was taken. Examine the information in the Feature Properties window.

The Airport Name was selected from a menu in the data dictionary (we knew which airports we would be flying to; IOB is the airport designation). The altitude from the altimeter was read directly from the instrument and typed into the laptop computer. The time was local time, based on UTC time taken automatically from the receiver. The published altitude, the runway number,[4] and the runway length were input after consulting an aeronautical chart. Notice the differences between the altimeter altitude (1,040 feet), the published altitude (1,020 feet), and the GPS altitude (taken from the Position Properties window) of 1,012.644 feet. The differences in these altitudes indicate why one doesn't want to use an altimeter altitude or a GPS altitude (even a corrected one) as the sole determiner of altitude when getting an aircraft on the ground. A matter of two or three feet vertically can make the difference between a smooth landing and a controlled crash.

{__} You can experiment by clicking on various icons in the Time Line window, in the Feature Properties window, in the Position Properties window and on the Map window. Sometimes these

---

[3] Aircraft altimeters must be set to the local sea level barometric pressure if they are to accurately represent altitude. The value 29.92 was used as the default because it is "standard pressure." That is, at sea level, on an average day in an average place, the atmospheric pressure will support a column of mercury 29.92 inches in height.

windows don't seem to be completely coordinated, but you can always ultimately get to view a given entity in several ways. Practice stepping through the various features from the first to the last.

{__} In the Utilities menu (or on the (Utility Toolbar) select Data Dictionary Editor ~ File ~ Open. Navigate to

__:\GPS2GIS\Flying_Tour\Apt_Info.ddf

and open it. This is the data dictionary file (ddf) that was used to create the features in R032720A.COR. Click on the various Features and Attributes to better understand the relationships between features, attributes, and values. I'll say much more about data dictionaries and their use in the following projects, but this exercise should give you the general idea of how it all fits together.

Three Linked Projects 7B, 7C, and 7D: Utilizing Feature Attribute Data

The following three projects (7B, 7C, 7D) relate to obtaining and converting feature attribute information as well as position data. If you have a GeoExplorer receiver and Pathfinder Office software, and you want to collect data in the field, do all three projects.

If you do not want to take time to collect data, but do want to see most of the conversion process, do projects 7C and 7D.

If you only want to see the results of feature data collection, and you have ArcInfo or Arc View available, do Project 7D. In any event, you should plan to read through all three projects.

{__} To do any of the projects, you should make a separate directory to hold the data. Assuming you have done previous projects and have a "DATA_yis" folder, make a new folder named FEATURES under it. Create a new Pathfinder Office Project, named FEATURES_yis, that references the new folder:

__:\GPS2GIS\DATA_yis\FEATURES

You will need this folder if you do any of the "attribute" projects. Make FEATURES_yis the current project.

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[4] If you zoom up on the southwest end of the runway you can see the runway number. Then pan along the path the aircraft took. Follow it into the parking ramp area. Then zoom to previous.

PROJECT 7B

Obtaining GIS Attribute Information with GPS Equipment

In the steps below you will make, in __:\GPS2GIS\DATA_yis\ FEATURES, a data dictionary using Pathfinder Office and the Still Simple Data Dictionary.

{__} In the Utilities menu select Data Dictionary Editor. Type Still_Simple as the name. Type in any Comment you wish. Plan to use the form, if not the exact text, from the Overview as a model for your data dictionary. (If you are in an urban area where rocks or trees are scarce, perhaps you could substitute TELE_POLES and PARAMETERS.)

A data dictionary is built with a series of windows. You are prompted for feature-type name, attribute, and other information, as appropriate. (Ignore fields that ask for user codes.) "OK" enters the particular entity; "Done" records your choices so far, then takes you back a level in the hierarchy. A "default value" is the one selected by the GeoExplorer at data collection time if you don't select another. As you build the dictionary you will see it appear in a box on the right of the screen. You should be able to make "Still_Simple" with just the information found in the Overview section and the steps below.

{__} Click New Feature. The first Feature Name will be Rocks. You may add a comment here if you wish. The Feature Classification is Point. Under Default Settings leave the Logging interval at 5 seconds and the Minimum Positions at 1. The Accuracy must be Code, not Carrier. OK the window. Notice that, back in the Data Dictionary Editor window, a record is being made of your progress, under Features.

{__} Click New Attribute. In the New Attribute Type window "Add" a "Menu" attribute. The name of the Attribute would be "Size." To specify the possible menu values click New. Type "Small" to make an Attribute Value and click OK. Now add "Medium" as an Attribute Value. Then "Large." Close the "New Attribute Value—Menu Item" window. Okay the "New Menu Attribute" window. Close the "New Attribute Type" window.

{__} From what you have just learned, construct the Color attribute of Rocks with the menu values Black, Gray, and White. Examine the specifications of the Still_Simple Data Dictionary described earlier in this section for the details.
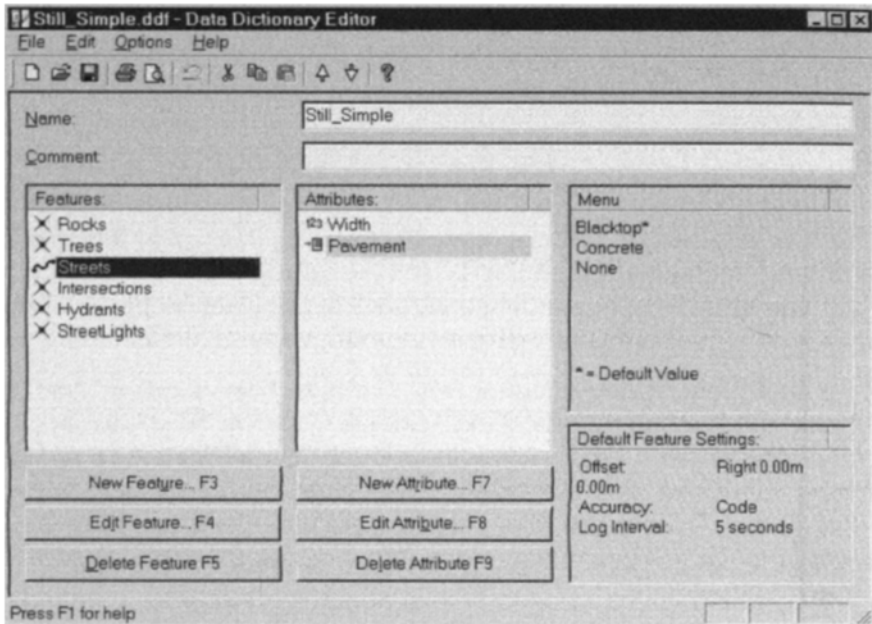
Figure 7–3. Making a Data Dictionary.

{__} ***Observe and experiment with the Data Dictionary Editor window:*** Select Rocks. Select Color. Use the F8 key to Edit the spelling of "Color" to make "Colour" and add "Pink" to the list of Menu Attribute Values.

{__} Delete "Pink" as a possible value. Go back to the American spelling of "Color."

{__} With the F3 key add the New Feature "Trees" with "Size" as a Numeric attribute with two decimal places. The Minimum should be 5; the Maximum 300. The default value—the one that will be used if the person doing the datalogging fails to put in a value—should be 10.

{__} Complete the data dictionary using Still_Simple as a guide. Figure 7–3 gives an idea of what it should look like, although there are many more facets to it than can be displayed in a single image.

{__} Once your dictionary is complete, step through the features and attributes (by clicking on them) while examining the pane that gives information about the possible values. Use the edit capabilities of the Data Dictionary Editor to make any needed corrections.

It is important to get the data dictionary correct NOW.
Once you get into the field you are stuck with what you have done.
And once you have collected data with a particular data dictionary
you become even more wedded to it. Get it right to begin with!

{__} Under File ~ Save As, allow the suggested "data dictionary
file" (ddf) name Still_Simple.ddf to stand, but put the file in __:
\GPS2GIS\ DATA_yis\FEATURES. Dismiss the Data Dictionary
Editor.

{__} Connect the GeoExplorer receiver to the PC as usual, setting
the proper communication parameters in both Pathfinder Office
and the receiver. Select "Data Transfer" from the main menu of the
receiver.

> With the Geo3, turn the unit on, fix up the communication
> parameters, and place it in the cradle, Just as you would if
> you were going to transfer files or an almanac. A primary
> difference between the two versions of the GeoExplorers and
> the Geo3 is that the Geo3 can memorize and use more than
> one data dictionary file.

{__} In Pathfinder Office, Transfer the almanac to the PC, just to
be sure the connection is working.

{__} *Transfer the "Still_Simple" data dictionary to the
GeoExplorer:*

{__} Press the Send tab (this time the computer is sending
information to the receiver, rather than the other way around) and
then Add ~ Data Dictionary. When the Open window appears,
navigate to

__:\GPS2GIS\DATA_yis\FEATURES. The file name
Still_Simple.ddf should appear in the window. Click on it, and then
click "Open." "Transfer All" should send the file on its way. When
done, check on more details, then dismiss the now unneeded
windows.

{__} With the GeoExplorer, under "Main Menu ~ Data Capture ~
Dictionary ~ Review" examine the data dictionary you just loaded.

{__} Disconnect the GeoExplorer from the computer. Set up the
receiver to collect position data. In addition to the parameters that
you have set before, set the following under "Configuration ~ Rover
Options":

• Set the "Not in Feature Rate" to 5 seconds.
• Make sure the "Hi Accuracy" setting is "off."

- Select Feature -
1.Rocks
2.Trees
3.Streets
4.Intersections
5.Hydrants
6.Streetlights

Streets 0
1.Close Feature
2.Pause
3.File Status
4.Main Menu
5.Nest Feature
Width 2
Pavement
Blacktop

- Under "Feature Logging" set "Points" to 5 seconds.
- Under "Feature Logging" set "Line/Area" to 10 seconds.
- Under "Feature Logging" set the minimum number of positions ("Min Posn") to 8.

These parameters will not give you particularly good accuracy, even if differentially corrected, but the object of this exercise is simply to have you practice collecting attribute data simultaneously with position data.

{__} *Collect some data while walking:* Pick a mile or two long road segment that contains several intersections. Take the receiver out and open a rover file under the "Data Capture" menu. Data should begin to be recorded in that file every 5 seconds.

{__} As you start your walk, go to "Select Feature." The "CMD" key here will give you a list of the possible features in the data dictionary, such as:

Pick "Streets." Data will now be recorded under that feature, so continue to walk. Note that the number of fixes recorded for the feature will be displayed in the upper right-hand corner of the screen. The following display will be presented.

{__} Since it may be difficult to enter data while walking, stop and select "Pause" to suspend data collection for the feature "Streets."

- Nest Feature -
1.Rocks
2.Trees
3.Intersections
5.Hydrants
6.Streetlights

Intersection 0
1.Close Feature
2.Pause
3.File Status
4.Main Menu
T_intersection
Not Entered

{__} Enter the value for "Width" as the number of lanes of the street. (If the number of lanes is two, you need make no entry, as this is the default value. Otherwise press "CMD" with the cursor over the "2" and adjust the number as necessary.)

{__} Enter the "Pavement" type by pressing "CMD" over "Blacktop." The menu of possible pavement types will appear. Select one of them.

{__} Resume data collection and walking.

> With the Geo3 you get to the main DATA menu. Select "Create new file," Highlight "Dictionary" and press ENTER. Select the "Still_Simple" dictionary. Return to the Data Menu. Do not press the "LOG" key!

{__} When you encounter a point feature that you would like to record— let's say an intersection—select "Nest Feature." The idea here is that you can record fixes for a point feature while taking data along a linear feature, i.e., you are nesting the point feature within the line feature. A menu of the possible "Point" features will appear:

{__} Select "Intersections." Fixes are now being recorded for that point feature, and you should begin entering the appropriate attribute data on a screen such as this:

{__} The data dictionary requires you to enter a "Yes" or "No" as to whether the intersecting street terminates at the street you are on

(that is, a "T" intersection) or whether it goes through. Select "Not Entered," then choose the correct answer.

{__} Observe the number of fixes that have been collected for the intersection. If eight or more, close the feature. Data taking will resume on the line feature "Streets," so resume walking.

> To nest features on a Geo3 is no more complicated but is a little less intuitive. Press the CLOSE key to temporarily close the Streets feature. From the resulting menu select Intersections and point fixes will begin to be collected for that point feature. Select the correct attribute value for T_intersection. Press ENTER, then press CLOSE. Now press OPTION!. Continue with the Streets feature.

(To close a feature that doesn't have any fixes—or enough fixes— put the cursor over "Close Feature" and press "CMD." If that doesn't work, put the cursor over "Close Feature" and press "Esc.")

If the GeoExplorer had a keyboard, entering text and numbers would be a lot easier. On the other hand, during a real data collection effort, you may have to occupy the point for a while so the limitation imposed by the receiver gives you something to do.[5]

> The Geo3 makes it a bit easier to enter alphanumaric characters. A "keyboard" appears that lets you select letters and numbers with the arrow keys. Select CLOSE on the "keyboard" or press the CLOSE button when done.

{__} Nest other point features (Rocks, Trees, Hydrants, etc.) that you find along the way, in addition to the intersections.

{__} At the end of your walk, close the feature "Streets."

> To close the feature on the Geo3 press CLOSE.

{__} Close the file.

{__} As you walk back, open a new file, and the feature "Streets" within it. Close the feature and the file at the appropriate time.

---

[5] As a math professor of my acquaintance once remarked, regarding whether an automatic transmission or a manual transmission was preferable in an automobile: "Well, you might as well shift the gears yourself, since you have to be there anyway."

{__} ***Load the data into your PC:*** Start the Pathfinder Office software. Transfer the two files you just collected to the project containing the data dictionary:

__:\GPS2GIS\DATA_yis\FEATURE.

{__} Differentially correct the files at this point if the base station files are available.

PROJECT 7C

This project is a continuation of PROJECT 7B, but initially uses some sample data provided in __:\GPS2GIS\FEATDEMO. I recommend that, even if you collected your own data in PROJECT 7B, you work through these PROJECT 7C exercises with the supplied data; then use the same process with your own data.

{__} Make (or change to) a Project named Feature_Demo. It should point to

__:\GPS2GIS\Feature_Demo.

{__} Arrange the Map, Time Line, Feature Properties, and Position Properties as you did in PROJECT 7A (see Figure 7–1).

{__} Set up the following parameters: Kentucky state plane coordinates, north zone, NAD83, survey feet for all linear measurements, time zone EST.

{__} Open F121723C.COR and, as a background file, FIVE.TIF. With View ~ Layers ~ Features make:

- Not In Feature data a thin red line
- Streets a thin yellow line
- Rocks a black dot with a yellow background
- Trees a green tree
- Intersections a black cross with a yellow background
- Hydrants a red hydrant
- Streetlights a gray streetlight

{__} Experiment with the Time Line (you can separate the features by zooming up in that window with the magnifying glass). With Auto-pan to Selection active, experiment with moving along the track with the Position Properties window. And then do the same with the Feature Properties window. Since the DOQ is not very high resolution, about all you can verify from the image is that the feature Intersection does indeed show up where there are intersections. Trees and such are not distinguishable. (See Figure 7–4.)

Figure 7–4. Using Pathfinder Office to view collected features.

The Geo3 equipment and pathfinder Officf software have option that let you specify an "offset" for features that are a distance away from where you are. For example, suppose a tree is some distance from the sidewalk you are taking as a line feature. You could input the distance from the receiver to the tree and indicate whether it was left or right of your path. You could even, with some equipment, connect a distance-measuring device (such as a laser range finder) to the GPS receiver to provide a more accurate distance. Using these options requires more depth than we will go into in this text. If you need such abilities, read the manuals that came with the equipment or contact the vendor.

Make ArcView Shapefiles from the Feature-Types[6]

The process of making ArcView shapefiles from GPS files containing feature attribute data is virtually identical to that described in Chapter 6a. The primary difference is that, instead of getting just one shapefile (posnpnt.shp or posnline.shp) you will get several:

- Not In Feature data will be in POSNLINE.SHP.
- Streets will be in STREETS.SHP.
- Rocks will not be represented as a shapefile since we didn't collect data for this feature.
- Trees will be in TREES.SHP.
- Intersections will be in INTERSEC.SHP, since Pathfinder Office only outputs the first eight characters of a data dictionary feature-type as an ArcView shapefile name.
- Hydrants will be in HYDRANTS.SHP
- Streetlights will be in STREETLI.SHP

{__} Start with the Export Utility. For the input file use F121723C.COR, which is in __:\GPS2GIS\Feature_Demo (pointed to by the Project named Feature_Demo).

   {__} The Output Folder should automatically come up as
   __:\GPS2GIS\Feature_Demo\EXPORT. Fix it if it doesn't.

   {__} *For practice make a New Export Setup:* Press the button "New Setup." From the drop-down list select Arc View Shapefile. The Setup Name will appear as "New ArcView Shapefile." Change it to "AV#4_yis." A window, Export Properties, will appear.

   Under the Data tab: for "Types of Data to Export" pick "Export All Features" from the drop-down list.

---

[6] With Pathfinder Office you may make either ESRI Shapefiles or ESRI Coverages. Chapter 6a demonstrated making shapefiles; Chapter 6b showed how to make coverages. In this PROJECT only shapefiles are dealt with. You can make coverages from shapefiles with the ArcInfo SHAPEARC command. Or you may look on the CD-ROM that accompanies this book in the Chapter 7 Addendum for a description of how to make coverages directly from Pathfinder Office. One reason for dealing only with shapefiles here is that Pathfinder Office will "automatically" make all the shapefiles for all the features at one time. With ArcInfo, you have to create each feature coverage separately, after editing the AML file. It's not nearly as clean.

For Output: Combine all input files and output them to the project export folder.

Under Attributes: Output the Time Recorded for All Feature-Types. For Point Features use the Height and the Point ID. For Line Features select the 2-D Length, the 3-D Length and the Line ID.

Units: You can use the current display units, since those let you see both the GPS track and features as well as the DOQ image. (You would have to be careful using the setup AV#4_yis in the future, since it would use the display units in effect at that time.)

Position Filter: make sure Differential is checked under "Filter by GPS Position Info."

Coordinate System: again, you may use the current display coordinate system.

The ArcView Shapefile tab, which allows you to Export Tracking Themes, needs no attention here.

ESRI has produced an ArcView extension called the Tracking Analyst that allows real-time tracking of GPS receivers, or "playing back" data taken by such receivers. There is some additional discussion of this ability in the next chapter. Basically, the Tracking Analyst allows the user to plot GPS data as it is being acquired, by virtue of radio transmissions, perhaps by communication satellite or cellular telephone, of the GPS data to a location that then relays these data to the ArcView software. If, for example a bus company wanted to know the whereabouts of each bus and whether it was on schedule, it might use the Tracking Analyst to display this information in real-time. Click OK to exit the Export Setup Properties window. If you need to make a change or to be sure you've made the right choices, you can select "Properties" in the Export window.

{__} When you are satisfied with the Export window, click OK. Pathfinder Office will commence making the shapefiles.

{__} Click the folder icon on the Project Toolbar to bring up the project folder. Double-click the Export folder icon. You will see three files for each feature-type. For example, HYDRANTS.SHP, HYDRANTS.DBF, and HYDRANTS.SHX. HYDRANTS.DBF is a database file that contains the attribute information about the hydrants. This information will appear in the ArcView table of HYDRANTS.SHP. HYDRANTS.SHX is a file that ArcView uses for its own purposes.

Now you may:

(a) examine your own GPS data file and turn it into ArcView shapefiles (use your Project named FEATURES_yis, that references the directory:

__:\GPS2GIS\DATA_yis\FEATURES)
 OR[7]

(b) proceed to examine the shapefiles you just made in ArcView in PROJECT 7D.

PROJECT 7D

Viewing Shapefiles

Here's a summary, mainly for those who didn't do the previous two projects: In PROJECT 7B we completed a data dictionary, installed it in the GeoExplorer, collected data under the structure of that dictionary, and brought those data back to the PC. In PROJECT 7C we looked at some similar sample data, and generated ESRI Arc View shapefiles.

From this point forward in the text, anyone with access to Arc View may process the files that resulted from the previous work.

{__} Start ArcView. Make its window occupy the entire screen. Make a new View. Make its window tall, occupying half the screen.

{__} Add the theme __:\GPS2GIS\Feature_Demo\EXPORT \STREETS .SHP (it's a Feature Data Source) to the view and turn it on. Make sure it is active.

{__} Open the theme table for STREETS.SHP. For each streets feature that was collected you should see a record giving both the features you specified when the data were taken (width and pavement) plus the features that were specified when you generated, with the export setup, the shapefiles. Any numeric units will, of course, be those you indicated at the time of export. Dismiss the table.

---

[7] This OR is called, in logic, the inclusive OR. It means either (a) or (b) or both. The exclusive OR means (a) or (b) but not both (a) and (b). English has both the inclusive OR and the exclusive OR; you must decide which is meant, based on context. Inclusive: "Would you care for cream OR sugar with your tea?" Exclusive: "You have won the contest and you may have a trip to Hawaii OR a new TV set."

{__} Add the Image Data Source FIVE.TIF from __:\GPS2GIS\ Feature_Demo as a theme. Drag it to the bottom of the table of contents.

{__} Make the View active again and add the feature-based theme INTERSEC.SHP. Turn it on. Make the cursor active with the Identify icon. Click on each intersection and verify that the T-Intersection designation (Yes or No) is correct. See Figure 7–5.

{__} Open the other shapefiles generated in the preceding project. Look at their theme tables.

{__} ***Display the "Bulb_type" for the streetlights on the map:*** Make the theme STREETLI.SHP active. Select Theme ~ Properties ~ Label Field ~ Bulb_type. Click the Label icon (looks like a paper gift tag with a string). Click each streetlight feature.

{__} If you have ArcInfo and wish to convert each shapefile into a coverage you may use the ArcInfo SHAPEARC command.

Now Use Your Data

{__} If you collected data in PROJECT 7B, go through the procedures of PROJECTS 7C and 7D, using your own data, using appropriate datum, coordinate system, projection, and units. Use the folder __:\GPS2GIS\DATA_yis\FEATURES that is specified by the Project you made in PROJECT 7B.

OVERVIEW

Planning a GPS Data Collection Session

Fact: In a given area, the GPS data collection process works better at some times than at others. Determining a good (or just satisfactory) time to take data is called **"mission planning."**

Several years ago, this discussion of mission planning would have had to appear at the front of the book, because there were so few GPS satellites in orbit that you had to go into the field at specified times to collect data. Now with the NAVSTAR system at full operational capability plus some 28 satellites up and healthy at the turn of the century you can almost always "see" enough satellites to get a pretty good fix. But is it a fix that is accurate enough to meet your needs? (Our needs in this book were simply to show you how the system worked. So we left the mission planning details until now.)
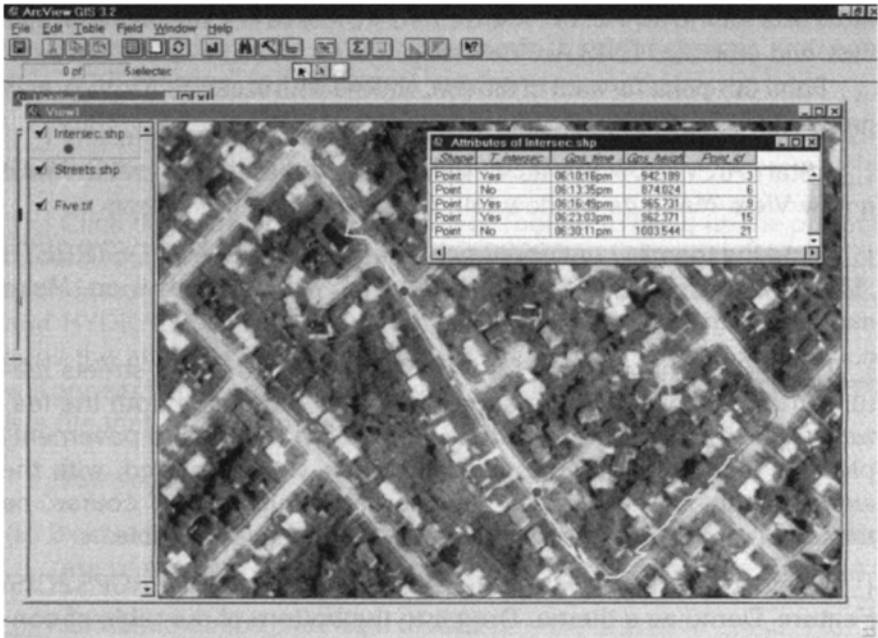
Figure 7–5. After Export, using ArcView to view features.

It might have been simpler if the GPS satellites were simply parked over various areas of the world so that, in a given location, you always dealt with the same set of satellites in the same positions. Unfortunately, this would mean that they were always parked directly over the equator, since, due to the laws of physics, that's where all geo-stationary satellites are. (If they were orbiting the Earth anywhere else, as they would have to be in order to provide worldwide coverage, they would be moving with respect to the ground underneath.)

So the rule for GPS satellites is "constant change." The number of SVs your receiver can track changes. The geometric pattern they make in the sky changes. The local environment in which you want to take data changes— perhaps there are blocking signals from reaching your antenna. If you want to collect data at the optimum times—for examples, when the DOP is very low, when there are enough satellites in the right part of the sky, or when there are a large number of satellites available for overdetermined position finding—you might want to use mission planning software.

This software will help you if your data collection effort might be impeded because there are barriers between you and some part of the sky. You may use the mission planning software to simulate such barriers and to tell you when the satellite configuration will be such that you can take good data anyway.

Almanacs

A GPS almanac is a file that gives the approximate location of each satellite. Actual position finding does not depend on the almanac; a much more precise description of each satellite's position is needed for a GPS fix calculation. (Precise descriptions of the orbit of a given satellite come from an ephemeris message—a broadcast that may change hourly—by the satellite itself.) Rather, the almanac is part of the general message which comes from **each** satellite, describing the orbits of **all** satellites. The almanac gives parameters from which the approximate position of all satellites can be calculated at any time "t" in the future.

Since it doesn't have to be very precise, an almanac may be good for months: left to themselves, GPS satellites deviate little from their projected orbits. However, the DoD may move a satellite forward or back within its orbit—perhaps to replace a failing satellite or to make room for the launch of a new one. Activities such as this make it necessary to collect almanac information frequently. In fact, the GeoExplorer collects an almanac every time it is outside and tracking one or more satellites for a minimum of about 15 minutes.

This almanac can be transferred to your PC. While the receiver will not tell you the almanac's age, the Quick Plan software (which is part of Path-finder Office) will tell you if an almanac is more than a month or so old.[8] An ephemeris file, from which Quick Plan may derive an almanac, may also be loaded onto a PC across the Internet from the Trimble Navigation web site.

Almanacs are used for at least two purposes:

- giving information to the receiver so that it can locate the satellites more quickly, and
- providing information to PC software so it can tell the user the best times to collect data.

It is this second purpose we examine here: using Pathfinder Office to tell us when we can get the best data at a given location.

Using Mission Planning Software

Trimble Navigation provides software to help the GPS user determine the best time to collect data: a program running Microsoft Windows called Quick Plan. Basically, Quick Plan gives you information about the expected behavior of the satellites. This is information you need for planning important GPS data collection sessions. To practice using the mission-planning software, do PROJECT 7E. To see the effects of poor mission planning, do PROJECT 7F.

STEP-BY-STEP

Planning a GPS Data Collection Session

PROJECT 7E

Setting Up for the Planning Session

The first chore that has to be done is to get current information as to where the satellites are into the Quick Plan software; there are at least two ways to do this.

1. You can go to a Trimble Navigation web page, which, at the time of this writing, is

    www.trimble.com/support/files/index.htm

    and download a file named current.ssf. You may put this file anywhere you want, but Pathfinder Office and Quick Plan use

    C:\Program Files\Common Files\Trimble\Almanacs

    as the default directory. This download process transfers an **ephemeris** file. An ephemeris file contains precise orbital information for each satellite; Quick Plan can derive an almanac from it.
2. You can transfer the almanac from the GeoExplorer. An almanac contains rough orbital parameters for every satellite in the constellation, and is broadcast, for all satellites, by each

---

[8] To find out the date when an almanac was received by the GPS unit use Checkssf utility: Utilities ~ Other ~ CheckSSFFILES. When the check is complete ask for "More Details."

satellite. An almanac file is about one-seventh the size of an ephemeris file.

{__} ***Prepare to get satellite position information into your PC:*** Plan to either transfer it from the Trimble Navigation web site, or get it from your GeoExplorer. (If you did Exercise 2–1 you have already transferred an almanac.) A complete almanac file is recorded each time the GeoExplorer is exposed to at least one satellite for more than 15 minutes. To check your unit for a complete file:

- turn on the GeoExplorer,
- let it complete its startup routine,
- get to the main menu,
- press and hold the on-off key, and
- observe the bottom line of the screen; you are looking for a capital "A," which indicates that the unit indeed has a complete almanac stored in its memory.

If, instead, you see a lowercase "a," the unit does not have a complete almanac and you will have to either take it outside to collect data for approximately 15 minutes, or find another source for an almanac. Of course, the almanac in your receiver may be old. When was the last time this receiver was outside?

{__} Assuming you are going to transfer the almanac, connect the GeoExplorer to the PC as though you were going to transfer position data files. Turn it on.

{__} Start up the Pathfinder Office software. Under the Utilities Menu pick Data Transfer (or use the Data Transfer icon on the Utilities toolbar). The Data Transfer window will appear. Verify that "Status" shows that the PC is connected to the GeoExplorer. For "Data Type" select "Almanac." If you want to change the destination directory to something different from

C:\Program Files\Common Files\Trimble\Almanacs

now is the time to do it.

{__} Press the "Transfer" button. You are given the option of providing a new name other than "almanac.ssf." If you want a different name type it in. A name indicating the date the almanac was taken might be useful. Okay the box. Click "Yes" to overwrite a previous file by the same name if you want the latest almanac to register. The transfer should take place, indicated by a progress bar.

{__} Click "Disconnect." Dismiss the Data Transfer window.

{__} Turn off and then physically disconnect the GeoExplorer from the PC. (And, disconnect the GeoExplorer from the power supply— at the large end of the cable.)

Planning for GPS Data Collection—Mission Planning UsingQuick Plan

Now that you are assured that you have an up-do-date almanac in the PC you are ready to plan the data collection session.

Quick Plan is a sophisticated GPS planning program that runs under Microsoft Windows (version 3.1 and later). Quick Plan exhibits some dramatic graphic representations of satellite position and geometry information. We will not delve deeply into Quick Plan, but you will see enough of it to let you know whether you want to learn more about it, which you can do from Trimble's GPSurvey Software manual.

{__} Back in Pathfinder Office, in the Utilities menu (or the equivalent icon on the Utilities toolbar) pick "Quick Plan." When the main Plan window comes up, cancel any subwindows. Make the window occupy the full screen. Under the Session menu, pick New Session. An Edit Point window will appear. Punch Keyboard. A different window (but still entitled Edit Point) will appear. Type in as the Name "GPS_yis" and click OK. This brings you back to the first Edit Point window, with GPS_yis also in the title.

{__} You can inform Quick Plan, by a variety of methods, the location at which you plan to take data. Let's just experiment with the three ways you can choose a location. Click on World Map. Either a Mercator projection or an image of a globe will be displayed. Let's get to the globe, which will look something like Figure 7–6. If you are not there already, click on the map a time or two until the "Globe" option appears. Click it. Click the globe itself. A dot cursor will jump to the closest city that is in the database. Its longitude and latitude will be displayed along with the city name. As you move the dot cursor the names of the cities it lands on will be displayed.

{__} Find the city in which you would most like to take GPS data (or just visit). You may have to turn the globe left or right, up or down. Neat, huh? Turn off the Rivers. Enhance your knowledge of geography. Click the "About…" button.
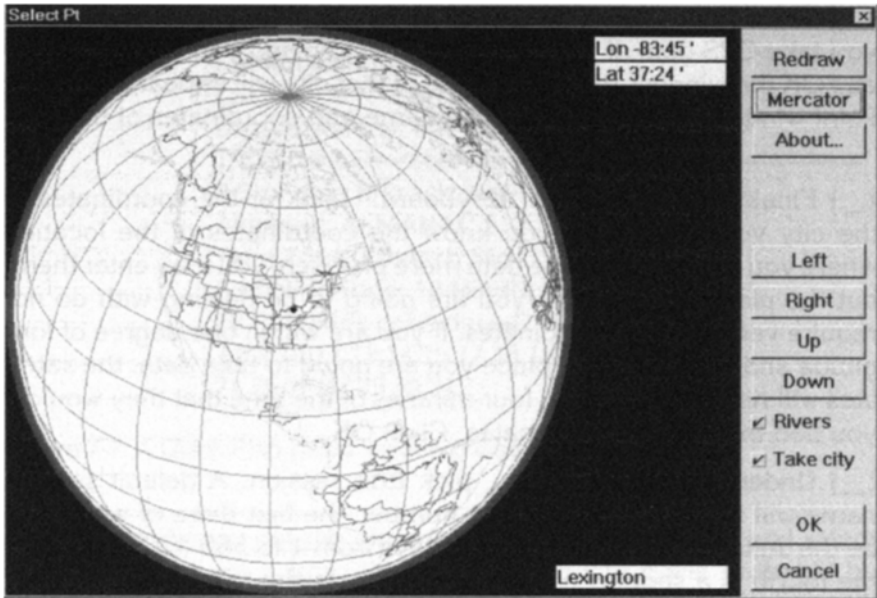
Figure 7–6. One way to select a city in Quick Plan.

{__} With "Take city" checked, click on Mexico City. What are its geographic coordinates? _____, _____. Click OK to get back to the Edit Point Screen.

{__} Pick "World Map" again and then get a Mercator projection of the Earth. Click on it until you can move the pointer around the screen so that city names appear at the bottom and the graticule coordinates show up at the top. After clicking on a Hawaiian city, magnify the Hawaiian Island chain. Again. Again. Again. Demagnify and Magnify as necessary so you can click on Kailua Kona on the island of Hawaii. You may recall this city from Chapter 3.

{__} Redraw the map so it goes to its extents. Select a city near where you take GPS data. If "Take City" is checked and you click on a city and OK the window, the coordinates of that city will appear in the Edit Point window. Click OK. Write the name and coordinates of the city: _____,_____,_____.

{__} Finally, click again on "Keyboard." Look at the coordinates of the city you selected. If you know the coordinates of the location where you are going to take data more precisely you may enter them, but the planning elements you are going to be dealing with do not require very precise coordinates. If you are within one

degree of longitude and latitude of the place you are going to take data, the satellites will rise and set within four minutes of the time that they would if you had the precise coordinates. Click OK.

{__} Under the Session menu, pick Edit session. A default session name will appear as a four-digit number, the first three of which will be the Julian date, numbering the days from 1 to 365 (or 366), while the fourth is a sequence digit. Click Edit. In the "all points" window you should see the point corresponding to the city you selected last. Click on it—then click "<Add<" to add the point to the empty list on the left side of the window. Okay the screen.[9]

{__} Click on "Date>>." Pick the date when you want to collect data. Click OK.

{__} A Status window will appear. (If the window such as that in Figure 7–7 is not on the screen, select "Options" from the main menu, followed by clicking on "Show Status.") Examine the status window. Check its text to be sure everything is correct. It may not indicate what satellites are tracked nor what almanac is used (as the one in the figure does). We'll fix that.

{__} From the Options menu pick "Time Zone." From the zone name drop-down menu, find your zone (remember about daylight savings time) and select it.

{__} Under the Options menu pick Almanac. In the "Load File with Almanac" window navigate to

C:\Program Files\Common Files\Trimble\Almanacs or to whrever you put the almanac that you transferred, and select that file. If you got it from the Trimble web site it will probably be named CURRENT.SSF. If you uploaded from a GPS receiver it will probably be called ALMANAC.SSF. Be sure you are looking for files with the extension SSF. From your experiences with Windows in general, or ArcView in Chapters 5 and 6, you should be able to navigate to this file, even though the names may be abbreviated. Ask your instructor, if you need help. When you okay this screen, the almanac will be loaded. The Status box will be much improved. Check that the correct almanac is employed. Notice the number of satellites considered in the planning session; they are enumerated. For an example see Figure 7–7. Dismiss the

---

[9] Quick Plan is a subset of a larger planning program for surveyors in which several sessions can be developed and saved even after the program terminates. This partly explains why there is a list of "all points" which contains only one—and why you have to transfer it to the current session.
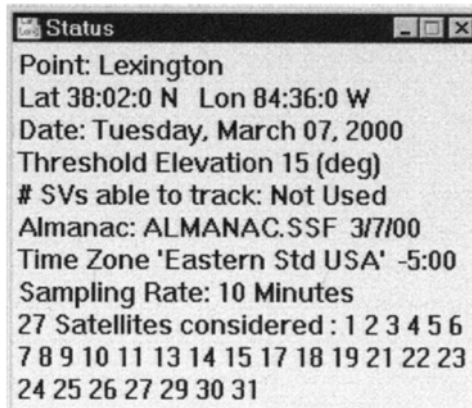
Figure 7–7. A Quick plan status window based on an almanac.

Status window (you can always get it back: Options ~ Show Status).

{__} Select "Graphs." Pick "Number SVs and PDOP." A graph with two parts will appear. Make it full screen. The graph should now appear something like Figure 7–8.

On the top you see the number of satellites that are visible above the elevation mask for a 24-hour session on the day you specified. The bottom shows the corresponding Position Dilution of Precision (PDOP), based on the number of satellites and their geometry.

{__} From this window you can probably get a pretty good idea of when, and when not, to collect fixes. You would avoid times of low satellite numbers and high PDOPs. (Leave this and subsequent windows open.)

{__} From "Options" set the "SV Sample Rate" to every 10 minutes.

{__} *A little side trip:* Sometimes, like for printing, you need a black and white representation. In the View menu click "Force MonoChrome." And how, pray tell, do you get color back? Click "Force MonoChrome" again! (I'd be willing to bet there is a little piece of computer code in Quick Plan that never gets activated. It says something like "Force Color.") If your computer setup allows you to print graphics, choose "Print Graph" from the "File" menu, printing in either monochrome or color, depending on your printer.

{__} Open up the "Azimuth" window (it's under "Graphs"). This shows the direction one would look in order to see each satellite. The satellite numbers appear at the top. What would you imagine
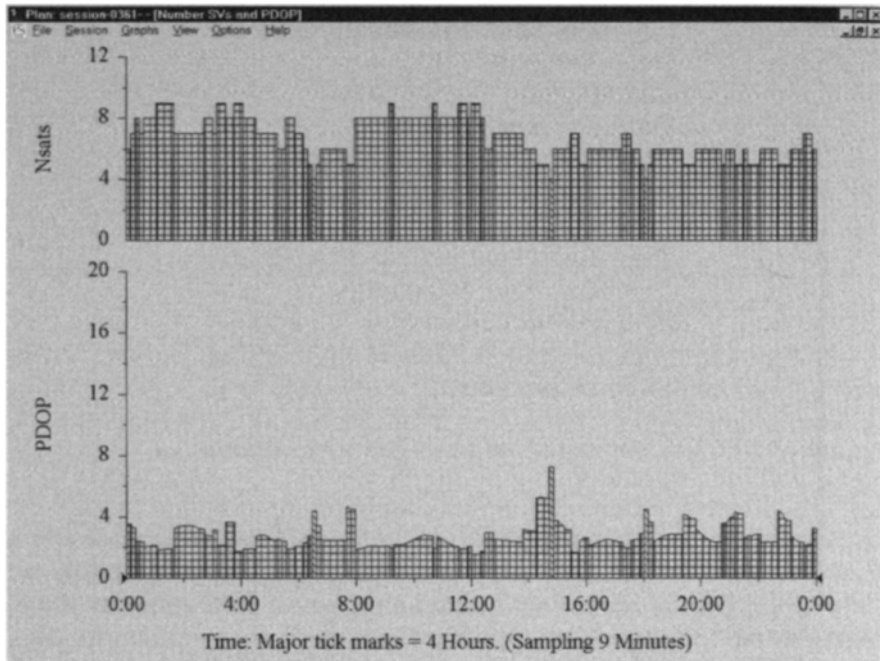
Figure 7–8. A Quick Plan graph of PDOP and number of satellites.

causes the jumps (sharp drops) of some satellite paths?

_____

{__} Open up the "Elevation" graph. You could use this information to pick a time when a cluster of satellites was high in the sky. Change the time period by picking "Mag" (for magnify) from the "View" drop-down menu. Magnify the time scale again.

{__} Open up the "Satellites" graph. This shows the times at which each satellite rises and sets above the local horizon.

{__} Pick a point on the time scale toward the right end, noting the time you choose. Click the left mouse button. Type the character "p." Note that the time scale shifts so that the time you picked is toward the center of the time scale. Now type "m." Now type "d" repeatedly. Note that you can get the day you indicated and all the next day.

{__} You can also adjust the time by sliding the little arrows that bracket the time line. Try this. Use View ~ Redraw (or just type "r") to get back to the 24-hour time line. Now look at the drop-down View menu to see what items you have been selecting with "m," "d," "p," and "r."

{__} Open up "SkyPlot," under "Graphs." You see the track of each satellite in the time period shown at the bottom. If you chose a location in the United States notice that the north area of the plot, which is centered on the geographic location you chose, has a dearth of satellites.

{__} Look at the SkyPlot of Figure 7–9. It covers the same two-hour period (the two hours after noon on St. Patrick's Day of 1996) as the SkyPlot of the first figure in the book, Figure 1–1. But it looks different, in terms of where the satellites are. Why? _____.

{__} Under "Graphs" choose "Tile 2 Column." If you haven't closed any windows you should see the all the graphs you have opened on the screen, with identical time periods. Close some so that you only have four showing.

{__} Choose "Redraw" under "View." This will restore the 24 hour time scale. And things will look pretty cluttered.

{__} Click the title bar in any window except the active one. It will become the active window, and will fill the screen.

{__} Under "View" pick "Close." Under "Graphs" pick "Close All."

Looking at Tables in Quick Plan

{__} Choose "Report Type" under "Options." You want the report that shows changes in constellations.

{__} Again under "Options," show the report. Use the "File" menu to print it. Upon examination, you can see that this would be a pretty effective planning tool, complementing the graphs. Dismiss the report by clicking once at the left of the report title bar and picking "Close." (It is easy to accidentally close Quick Plan completely here, so be careful.)

{__} Just for illustration, change the "Elevation Mask" (under Options) to 45°. degrees. Examine the same report and note the few times you would have enough satellites to collect data. After examining the table, choose the graph that shows the number of satellites and the resulting PDOR Apparently those satellites between 15° and 45° are vital to position finding.

Experiment

{__} Make a Sky Plot. Note the broken red line between the two inner-most circles. That is the 45° line. While all satellite tracks
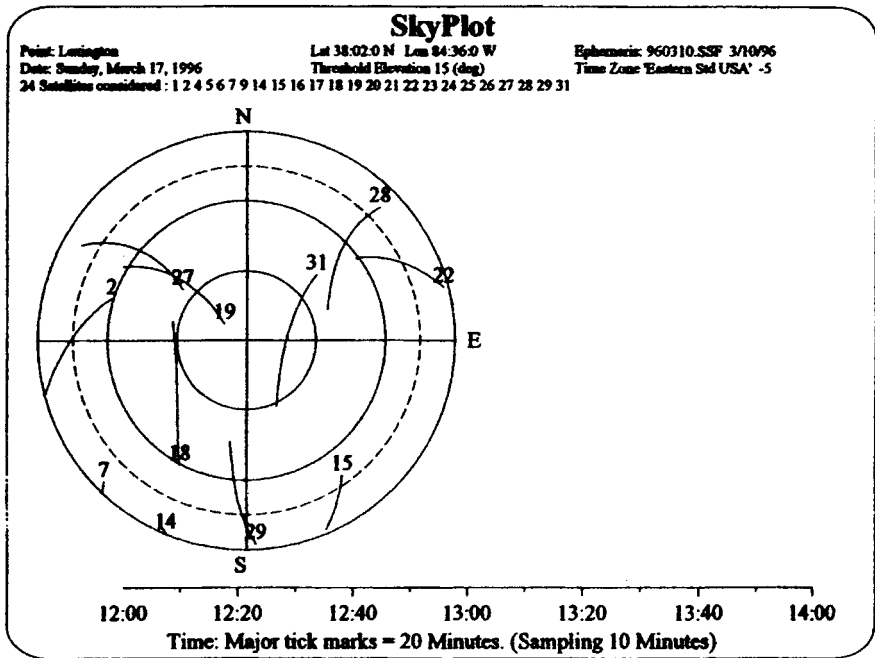
Figure 7–9. A Sky Plot looking from space at Lexington, Kentucky.

are shown, only the ones within that circle would be considered by a GPS receiver with the elevation mask set to 45°.

{__} Change the elevation mask back to 15°. Close all graphs and tables.

You can see the power of Quick Plan. It's also fun for those who like geography. Here are a couple more exercises.

{__} Under "Session" Pick "Create>>" to make a new point. Push Keyboard. Call the new point "North Pole" and make its coordinates 90°00'00' N and 0°0'0"W. Remove any existing points from the session and add North Pole. Set the elevation mask at 47°. Make a full screen Sky Plot. Note that the satellites never get above 47° in latitude. Note that there is an organized regularity to the paths of the satellites. Look at the Elevation graph. Bring up the Azimuth graph. Set the Elevation Mask back to 15°.

Bring up the graph that shows number of satellites and PDOP. Tile 2 Column. Note that you can get good PDOP even at the North Pole. It truly is a ***Global*** Positioning System.

{__} Edit the point of interest so you remove the North Pole and bring back your own city.

When the Sky Isn't Clear

As you have no doubt discovered by now, when you are taking data with a GPS receiver, a major factor is sometimes obstructions that prevent signals from reaching the antenna. One of the really nice features of Quick Plan is that it lets you simulate, in terms of sky obstructions, the points at which you are going to take data.

{__} Bring up the graph of Number SVs and PDOP. Tile it in 2-column format so it occupies half the screen. Edit the session (Session ~ Edit Session ~ Edit). Click "Curtain>>." Rearrange the windows so they look like Figure 7–10. In the Curtain editor click Options ~ Grid once. Suppose you want to represent an obstruction beginning at 120° azimuth that starts at 30° elevation, rises to 60° elevation in the due south, and returns to 30° elevation at a 240° azimuth.

{__} Position the cursor at Azimuth 120 and Elevation 30. (You can do this roughly from the diagram and check the Sky Coords box for the precise position.) Click. Now move the cursor (clockwise) to Azimuth 180 and Elevation 60. Click. Now to Azimuth 240 and Elevation 30. Click. **Right** click.

{__} Look at the graph at the left while you press Save Curtain. Note the dramatic change in the number of satellites and PDOP.

{__} Bring up a SkyPlot. The dark tracks indicate the positions of satellites blocked out by the curtain. Dismiss the SkyPlot.

{__} Click Edit ~ Clear. Answer OK. Then Save Curtain to save the cleared curtain which restores the obstruction-free situation so that no obstructions are saved with the point. Click OK under Sky Coords. Play some more, checking out the various options. If things don't seem to go right, exit the curtain editor and reinvoke it. At the end you need to clear the curtain and save the cleared condition. Otherwise the curtain stays associated with the point.

PROJECT 7F

This project will illustrate how taking data at the wrong time can result in loss of data. A route was driven at a time when only five satellites were visible. The same route was driven later when seven satellites could be tracked. The graph showing the PDOPs and number of satellites during the two-hour time frame that covered both data collection sessions is shown as Figure 7–11. You can note that a bit before 4:00 P.M. (1600 hours) the number of satellites is five and the PDOP is six. Just after that time the
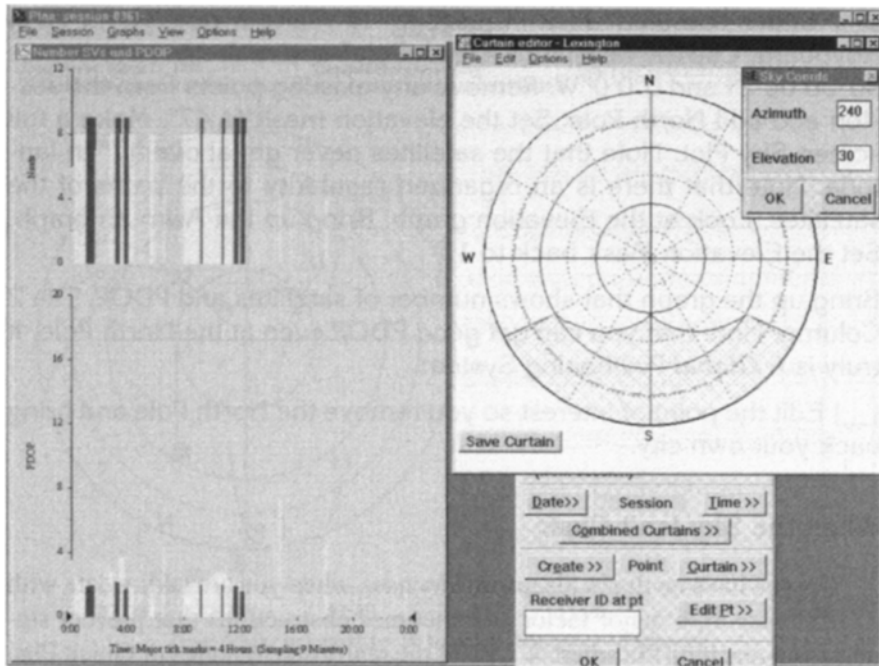
Figure 7–10. Simulating obstructions blocking the southern sky.

PDOP drops to approximately two and the number of satellites increases to seven. You would expect, in general, that a higher number of satellites would result in a lower PDOP, since a greater number of satellites allows for more choices of four-satellite constellations. Figure 7–12 shows a Sky Plot of that same time period. In the following steps you will be able to see the effect of choosing a better time to take data.

{__} In Pathfinder Office, navigate to __:\GPS2GIS\Planning and open the file From_UK_1. COR. Set up View ~ Layers ~ Features so that each Not In Feature fix is shown with a moderately thick red dot and that the dots are not joined. Bring up the background files one.tif through six.tif. From the Position Properties window locate the First fix. Note that it was taken at about 3:30. When was the last fix taken? ____. Notice the sizable break in the GPS track near the southern end. More than half a mile seems to be missing just north of the highway interchange.

{__} Open From_UK_2 (only), which constituted the same drive taken starting about 40 minutes later.[10] Now the trail of fixes is more complete. In fact, if you zoom up on the track where it appears to loop, you see that it shows an unexpected side trip that
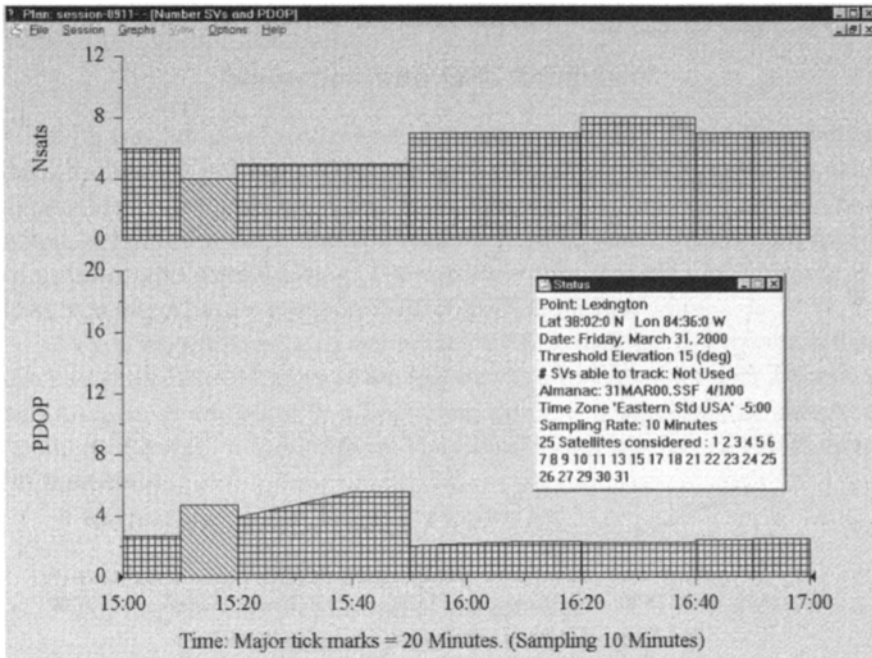
Figure 7–11. PDOP & Nsats of when to take data and when not to.

the car made: it turned into a bank driveway, circled the bank, turned right (heading north), then left on side roads to rejoin the main road going south. (The previous trip had done this as well but you couldn't see it because of the data loss.)

{__} Look back at Figure 7–11. Starting the data collection session 40 minutes later made a real difference in the satellites available and the PDOP. And this made a significant difference in the data fixes that were collected!

As with the rest of Pathfinder Office, Quick Plan has features we have not experimented with. Check out the rest of the menu options if you wish. Consult the Help files. Consult the manual.

---

[10] Okay, so it was a day and 40 minutes later. The same constellation was available, since the difference is only four minutes a day. The satellites arrive at the same point in the sky just four minutes earlier each day.
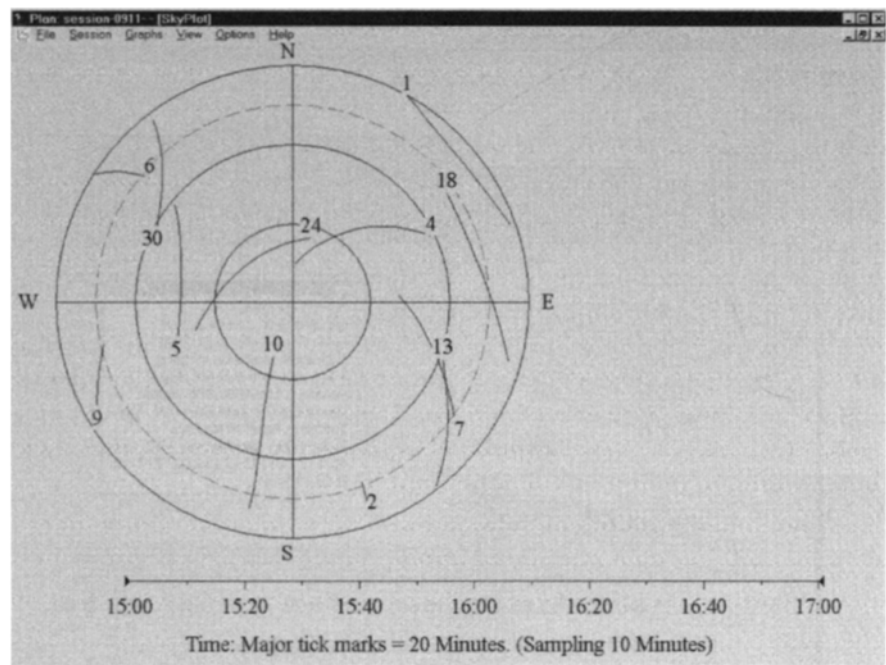
Figure 7–12. Sky Plot of when to take data and when not to.

OVERVIEW

Navigation with GPS Equipment

GPS was not developed primarily to allow users of GIS to obtain better data. Rather, the purpose, which we have virtually ignored in this text, was to provide better navigation and instantaneous position information. You noted, back in Chapter 1, that you could determine your direction and speed of travel as you were walking. The software built into the GeoExplorer allows you to perform a number of other navigation functions.

As you may remember, a waypoint (WPT) is a single, 3-D position that can be stored in the memory of the receiver as a special point with a number and a name. A waypoint is a beginning point, a destination, or simply a "point on the way" to somewhere. The GeoExplorer receiver can store up to 99 way points.

A waypoint can be set up in the receiver by:

- Navigation -
1.Start Navigate
2.To Waypoint
3.From Waypoint
4.Waypoint Setup
5.Display Format

- manually entering the coordinates of a point, or
- copying the current position of the receiver.

Obviously, before you enter any waypoints manually you must be certain that the datum, coordinate system, units, and altitude reference are set properly in the receiver.

Once a waypoint is stored, you can navigate to it by reading various screens on the receiver.

To look at how the GeoExplorers do navigation (while sitting in your easy chair), do PROJECT 7G. To practice (outdoors) using the navigation abilities of GPS, do PROJECT 7H.

STEP-BY-STEP

Navigation with GPS Equipment

PROJECT 7G

In this project we will look at the various options for navigation.

{__} Redo (or at least reread) the last few steps of PROJECT 1B that dealt with navigation using the GeoExplorer. The section starts with "Did the Earth Move?"

{__} In the office or lab, set up your GeoExplorer: Under "Configuration ~ Units ~ Custom Setup" set the distance units to kilometers, the altitude reference to MSL, the north reference to true north, and the angular units to degrees.

{__} Under "Configuration ~ Coordinates" choose "Deg/Min/Sec."

{__} From "Position" on the main menu, determine the longitude of the "Old Position." Write this value down.

{__} Go to the "Navigation" screen. It looks like this:

{__} Select "Waypoint Setup." The resulting screen appears:

{__} Select "Edit WPT." The up and down arrow keys change the number of the waypoint to be modified. Press the up arrow key until you find an unused waypoint (one with zero longitude and

- Waypoint Setup -
1.Add Here
2.Edit WPT
3.Delete WPT
4.Clear All

zero latitude). Press "CMD." Note the number of the waypoint (Wnn) that you are working with.

{__} *Give the waypoint the name "NP" for "north pole":* Use the up-down arrow keys to highlight the top line. Press (or press and hold) the right arrow key to move the highlight to a single position to the right of the waypoint number. Press the up arrow until an "N" appears. Use the arrow keys to place a "P" next to it. (If you want to spell out "North Pole" and your thumb is up for it, go ahead. The lowercase letters are after the "Z.")

At this point you want to move on to the next field ("Lat"). If you press the down arrow key you merely get the next letter. If you press "CMD," you are asked if you want to save the waypoint. If you press "Esc" you are returned to the "Edit WPT" screen. So how do you move to the next line? This is where the previously unused "enter" key comes in. (It's the key at the upper right with the bent arrow on it.) Press it.

{__} Edit the "Latitude" using the same technique. Make it 90° North.

{__} Edit the Longitude. Make it the same as your current longitude (as indicated by "Old Position," which you previously wrote down). Make sure you pick "East" or "West" correctly. (In virtually all the United States, pick "W.") (What state is northernmost? What state is westernmost? What state is easternmost?)[11]

{__} Edit the Altitude. Make it zero.

{__} Press "CMD." Save the waypoint.

{__} Find another blank waypoint. Edit it so that its name is "Eq" and that it represents a point on the equator (latitude zero degrees, longitude at the longitude of "Old Position," and altitude of zero.

In the next few steps you are going to explore the idea of a journey, first from your current position to the North Pole, then from your current position to the Equator. The sum of these two distances is interesting, in terms of the definition of the length of the meter.

- Display Format -
1.Dist/Bearing
2.Track & XTE
3.East/North
4.Velocity/Time

- Old Navigation -
Dist: 5795.9Km
Turn: left 118
Bearing: 0 Tn
Heading: 118 Tn

{__} Go to the "To Waypoint" screen. Press the up or down arrow keys until the "NP" waypoint appears. Press "CMD."

{__} Go to the "From Waypoint" screen. Press the up or down arrow key until "00" appears. Note that it is named "LAST POS" and has the coordinates of the last position recorded by the receiver. Press "CMD."

{__} Go to the "Display Format" screen which looks like this:

Choose "Dist/Bearing." This will set the display so that distance and bearing are revealed during navigation.

{__} Although you are planning to stay in one position for the moment, begin the navigation process with "Start Navigate." You will see something like:

Most of the items on the screen won't make sense, because you are shielded from the satellites, and you are "proceeding" on the basis of "Old Navigation." But the distance should be the distance from "Old Pos" to the North Pole and the bearing should show zero degrees. The heading, based on "true north" (Tn) and the amount you are to turn to get on course, should be the same. Write down the distance measurement: (OldPos_to_NP= _____ km.)

{__} Leave "Navigation" and configure the receiver to operate with a magnetic north reference. Then return and start the navigation again. The bearing now should reflect the magnetic variation (the difference between true north and magnetic north) in your part of the world. How much is it?

{__} Make "Eq" the "TO" waypoint. "Start Navigation." What is the distance from your position to the equator? _____ Add this

---

[11] Alaska. Alaska. Alaska.

distance to "OldPos_to_NP" which you wrote down earlier. The total should be about 10,000 kilometers. What is it? _____ [12]

{__} Change the display format to "East/North" and restart navigation. Here you are told how far to proceed in each of three dimensions to reach the destination waypoint.

> The designers of the Geo3 have gone to considerable lengths to make the unit "navigation friendly." One of the three main menu items (and hence the three white buttons) on the receiver is named "NAV." The unit even contains an internal compass—albeit a very imprecise one (it gives the direction the front of the unit is pointing to the nearest 45°). One thing the designers did not do is fix it so the last position is retained in the receiver after the power has been off. So you have to take it outside long enough to collect a position, to do the equivalent of the above. While you are outside waiting for the first fix to occur, use Fn-OPTION ~ Setup—Configurations (using CLOSE as necessary to get to the right place) to set Distance units to kilometers, North reference to True, and Degrees to DD*MM'SS.ss."
>
> After you have done that, being sure that the unit calculated a position, come back inside and press the "NAV" button. You will get one of three file tabs that relate to the three navigation options the user has: Chart, Road, and Compass. Press NAV until you get "Road." Basically the Road option lets you visualize your present position (where you see a little person icon) with respect to a **"target"** symbolized as a pair of crossed flags. The emphasis is on providing information, both numerical and graphical, to aid the user in moving to the target.
>
> To use this option you need to set up a target We will do that with a waypoint—the North Pole. To set it up, press the Option key, then highlight "New Waypoint" and press Enter. A screen with a waypoint name— something like OldGPS007—will appear. Our plan will be to establish the waypoint at the last GPS position and then edit it
>
> Press Enter. Use the "keyboard" to enter NP, after backspacing over OldGPSetc. Close the keyboard Press OPTION, select "Here." This puts the old position into the Latitude, Longitude, and Altitude fields if they aren't there already.
>
> Press Enter. Make the Latitude 90°. Leave the Longitude alone. Make the Altitude zero. Press CLOSE until the Road screen reappears. Press OPTION, highlight "Select target" and press ENTER. Scroll down to "NP" and press ENTER. On the ROAD screen you will see the person icon in the center and the flags at one end of the road. If you point the unit in different directions you will notice the road

---

[12] The meter was originally defined as what was thought to be 1/10, 000,000 of the length of the distance from the North Pole, through Paris, to the Equator. They missed by a little.

rotates as well. Point the unit so that the flags are furthest from you, as though the person icon is walking forward toward the target. That direction should be approximately north.

Press OPTION and activate "Info windows," which lets you select what items of information you want displayed at the bottom of the Road screen. With the ENTER key put checks beside Distance, Bearing, and Heading, and return to the Road screen. Distance is the distance to the target Write it here:_____. Heading is the direction the unit is pointed in. Since you aren't moving and receiving GPS signals, the Heading is taken from the internal compass. Bearing is the direction you would have to go from your present position to get to the target It should say 360°, since you go directly north from anywhere to get to the north pole. Presstiie SYS button and changethe "Morth reference" to "Magnetic"

Press the NAV button and observe the Bearing, You would have to go this Section to get to the target This tells you the magnetic variation in your area: ____. Experiment with selecting other Info windows—you can have two or three, depending on their widths

Now make a waypoint called "Eq" that represents a point on the Equator at your Longitude and an Altitude of zero. What is the distance to that waypoint? _____ The sum of the two distances should be about 10,000 kilometers.

I have chosen these obvious (and impossible) targets to give you an intuitive idea of how the navigation process works. You may also navigate to features that you have collected. This is an important advantage of the Geo3, since databases need not only to be built, but to be updated. You can transfer a GPS file back into the Geo3 (even from a GPS) and then navigate to its features to make changes or corrections.

If you press the NAV button (or use Fn-OPTIONS) you can bring up the "Compass" screen. Besides the appearance, the primary difference between this and the "Road" choice is that there is no "Road Scale" and there is a Calibrate compass option. (Check the Trimble manual for how to do that if your compass seems confused.)

One might wonder why they bother with two such similar screens. One advantage is that you can put different "Info windows" on the two screens and flip back and forth between them. Since you can have only two or three windows out of more than a dozen possible, this provides a way to get more information while navigating.

The final navigation choice is "Chart" which is considerably different. Using Chart is left as an exercise in reading manuals and experimenting.

PROJECT 7H

{__} With a map that has geographic coordinates on it, set up the GPS receiver with a nearby waypoint.

{__} Take the receiver outside so that it is calculating positions. Walk (or, if you have the remote antenna and wish to, drive) with it and experiment with the various display formats and the information presented.

{__} Navigate to the waypoint you set up.

OVERVIEW

Real-Time, Differential GPS Position Finding

You learned about differential correction in Chapter 4. We discussed postprocessing correction in some detail. While you can get more accurate fixes from such a system, it requires a number of additional, time-consuming steps, after data collection. Once you know the source of the differential corrections file, you have to get it, load it onto your computer, and execute software to produce the final corrected file. Wouldn't it be nice if the GPS unit simply gave accurate positions at the time you took the data?

Further, there are some applications in which there simply isn't time to postprocess GPS fixes—bringing a ship into a narrow harbor, for one example.

Well, actually there is a way to provide instantaneous, accurate fixes: Real-Time Differential GPS.

Getting Corrections for GPS Measurements— Right Now!

Real-Time Differential GPS (RDGPS) may be approached in several ways:

- The user can set up a base station over a known point and arrange for transmission of a radio signal from the base station to roving receivers.
- The user's GPS setup can receive correction signals broadcast from an antenna in the area operated by a corporation or a government agency. Such installations operate a base station continuously and broadcast the correction data, sometimes as part of another signal such as a standard FM broadcast. The U.S. Coast Guard maintains such a service in some coastal areas, and companies such as Accupoint, Inc. and Differential Corrections, Inc. sell a correction service.

• The user's GPS setup can receive correction signals from a communications satellite parked over the Equator. These signals come from data taken by base stations located in disparate parts of the United States. The data are analyzed, packaged, and sent to a geostationary communication satellite for rebroadcast to Earth. One such system uses this approach with a satellite located on a meridian that passes through Lake Michigan.

With all three of these methods, many of the requirements for base stations remain the same. They must take data from all satellites that the rover might use. They must take data frequently (every few seconds). They should have a separate channel for each satellite so as to track it continuously.

With all the methods of doing real-time differential correction, you might wonder how these pieces of equipment manage to talk to each other. While the frequencies on which broadcasts take place may vary, the content of real-time differential correction data is standardized. The current standard is RTCM SC-104 (version 2), promulgated by the Radio Technical Commission for Maritime Services, in Washington, DC. Look in more detail at the three steps for real-time differential correction.

A User-Operated Real-Time Base Station

The user may operate her or his own base station. Those who need really precise coordinates relative to some nearby known point (e.g., land surveyors) use this method frequently. The complications go up with differential correction (real-time or otherwise), of course. Here the user has to have at least two GPS receivers, plus a transmitter associated with one of them (the base station) and receivers for each rover. In addition to the roving GPS receiver and all of its settings and conditions for good position finding, the user has to also be concerned about the same factors for the base station, plus making the radio link between the stations function at some distance. Additional complications relate to mounting the base station antenna at a precisely known point.

A Centrally Located Real-Time Base Station

Since GPS signal errors tend to be quite similar over wide geographic areas, there are obvious advantages to having a single

base station serve for any roving stations in that area. Put another way, one can think of very few, if any, reasons for each of 28 GPS users, who are in reasonably close proximity to each other, to collect and rebroadcast identical correction data. This obvious fact, plus the entrepreneurial nature of American society, has produced GPS differential correction services, wherein a user contracts for equipment and the right to receive corrections to the raw GPS signal. Users who are sufficiently close to a U.S. Coast Guard GPS beacon may pick up a signal at no cost besides that of the receiving equipment. Such stations are sometimes referred to as Continually Operating Reference Stations, CORS.

A "Differential Corrections Anywhere" System

The problem with "centrally located" base stations is that there may not be a signal from one where you are trying to take data. While there are more and more base stations every month, vast gaps exist where their signals do not go. A solution to this problem is a system in which the broadcast of the correction data comes from a communications satellite. This means that, for a large portion of the Earth's surface, the user's receiver is never out of range in the area covered by the satellite, though local topography may block the signal. The satellite of one system that currently employs this method (OMNISTAR) might be as low as 30° above the horizon in northern parts of the United States. The satellite broadcasts a straight-line signal of about 4000 megahertz. The area covered is all of the United States (except parts of Alaska) and parts of Canada and Mexico. Another system that provides a similar service is Racal Landstar. Both systems provide coverage over large parts of the earth.

OMNISTAR has about a dozen base stations located on the periphery of the United States. These stations transmit data regarding the errors in the GPS signals in their areas to a central network control center. These data are then analyzed and repackaged for transmission to the communications satellite.

The broadcast from the satellite is such that the data from the several stations can be tailored to the user's position. How does the OMNISTAR system know where the user is? The user's GPS unit tells its coordinates to the attached OMNISTAR radio, which then decodes the signal from the communications satellite to provide the proper corrections for the local area. Since real-time differential correction information is useless unless it arrives at the GPS

receiver within moments of the time a fix is taken by the receiver, you can see that a lot has to happen in an extremely short amount of time. (A GPS signal code leaves a GPS satellite; it is received by your receiver and by the OMNISTAR base stations; the base stations transmit the signal to a central location where it is processed and sent to the communications satellite, where it is resent to the radio next to your GPS receiver; that radio determines the correction your GPS receiver needs and supplies it. Whew!)

This system can provide measurements such that 95% of the fixes taken lie within half a meter of the true point, and the mean value of a number of points is accurate to within a centimeter (horizontally), using a top-of-the-line survey grade receiver. With a GeoExplorer, you can expect 95% of the fixes to lie within nine meters, with means within two meters of the true point.

To practice using real-time DGPS, do PROJECT 7I.

STEP-BY-STEP

Real-Time, Differential GPS Position Finding

PROJECT 7I

Real-Time Differential GPS Position Finding

This project assumes that you have access to equipment that will permit real-time differential correction. Such equipment might be:

• A second GPS receiver, set up over a known point, transmitting RTCM form data that your GeoExplorer can receive if a separate radio is attached to it.
• A radio receiver connected to your GeoExplorer that is within range of a U.S. Coast Guard differential GPS beacon.
• A radio receiver connected to your GeoExplorer that is within range of one of several commercial DGPS service facilities (e.g., Accupoint or DCI).
• A communications satellite antenna, receiver, and demodulator, connected to your GPS receiver (i.e., OMNISTAR, Racal Landstar).

Because of the wide variety of equipment configurations that can be used for differential correction, the following steps can only serve as indications of what is to be done.

{__} Before leaving your lab or office, make sure you have a good idea of what you are about to do. RDGPS is wonderful, in that it provides you with accurate fixes instantaneously. The downside is that you have a lot more equipment to cart around, connect, and supply electrical power to. Make sure you understand and check out all the connections prior to taking the units into the field. Data packets flow between the radio[13] and the GPS receiver through the "download" cable you used when transferring files from the GPS receiver to a PC.

{__} Find a site at which to take data. If you can, find a site with the following characteristics:

- A known location, e.g., a survey monument or benchmark.
- A clear view of the sky for receiving good GPS signals.
- Within range of a ground-based RDGPS signal, or, if you are using OMNISTAR or Landstar, with a clear view of the sky to the south where the communications satellite is parked. (This is over the Equator, due south of Lake Michigan, for OMNISTAR.)
- Where a source of power is available for the auxiliary radio receiver (possibly an automobile auxiliary power receptacle or an additional battery pack).

{__} Start acquiring GPS signals with the GPS unit.

{__} If you can, assure that the RDGPS radio is receiving signals from the transmitting unit, but do not yet connect it to the GPS receiver.

{__} Using the parameters for data collection provided earlier in this text, collect a file of about 20 fixes, using a time interval of five seconds.

{__} Connect the output cable from the radio to the "download" cable from the GeoExplorer.

{__} Under "Configuration ~ RTCM" you will find this menu:

{__} Choose "Mode." You will see these options:

---

[13] We will use the term "radio" to mean the unit which receives and processes the RTCM signals from the base station and passes the information on to your GPS receiver.

```
┌─────────────────────┐
│     - RTCM -        │
├─────────────────────┤
│ 1.Mode  GPS        │
├─────────────────────┤
│ 2.Port B           │
├─────────────────────┤
│ 3.Stale time  010  │
├─────────────────────┤
│ Msg Count   0      │
├─────────────────────┤
│ Msg Gaps   0       │
└─────────────────────┘

┌─────────────────────┐
│     - Mode -        │
├─────────────────────┤
│  Autonomous        │
├─────────────────────┤
│  Differential      │
├─────────────────────┤
│  Auto GPS-GPD      │
└─────────────────────┘

┌─────────────────────┐
│  - Comm Port A -    │
├─────────────────────┤
│ 1.Protocol XMDM    │
├─────────────────────┤
│ 2.Baud  9600       │
├─────────────────────┤
│ 3.Parity None      │
├─────────────────────┤
│ 4.Data Bits 8      │
├─────────────────────┤
│ 5.Stop Bits 1      │
├─────────────────────┤
│ 6.Precision 2      │
├─────────────────────┤
│ 7.Send At 2s       │
└─────────────────────┘
```

- "Autonomous" means the receiver calculates only unconnected GPS positions.
- "Differential" forces the receiver to calculate, present, and/or file only positions corrected by RTCM signals.
- "Auto GPS-GPD" tells the receiver to calculate corrected positions when the RTCM signal is available, and to calculate uncor rected positions otherwise. (The uncorrected positions can be corrected later by postprocessing if you wish.)

{__} Choose "Differential." This is also shown as **GPD** mode on some GeoExplorer screens.

{__} Under "Port" you probably want "A," but this depends on the requirements and cables related to the radio. Once you select the port, you must select the communication parameters that relate to that port by choosing options on a screen like this:

{__} *Change the Protocol:* The default protocol is XMDM, which is used when the GPS unit is communicating with a PC. You need to change this setting to the one appropriate for your radio. Probably this will be either "RTCM"[14] or "RTCM/NMEA."

The GeoExplorer has the ability to send its position and velocity data through the data cable in a format called "NMEA 0183."[15] You use this capability with a device that wants to know where your receiver is, such as the OMNISTAR or Landstar radio.

(With most methods of real-time differential correction, the approximate location of your receiver is not a mystery, because it has to be within range of a signal generated locally and transmitted from an antenna on Earth. But the OMNISTAR or Landstar signal comes from a satellite 22,000 miles away and can be used almost all over the United States [and in parts of Canada and Mexico]. Since differential corrections vary from place to place, it is important that you receive the signals tailored for your area. Thus your receiver must tell the OMNISTAR or Landstar radio where it is.)

See the RDGPS-receiver-operation manual for specifics on the protocols for sending data from the GPS unit to the radio.

{__} Set the baud, parity, data bits, and stop bits as required by your radio.

{__} If you are using the RTCM/NMEA protocol (as you would if you were using OMNISTAR or Landstar) you must set the NMEA precision, which indicates the number of decimal places in the latitude and longitude output. A value of "2" is suggested. (This provides for a precision to the nearest 0.01 degree. That increment of latitude amounts to about 0.7 miles—certainly close enough to choose a differential correction area. The rule of thumb is that each 60 miles on the ground generates about a 1 meter error in the reading.)

{__} Set the output rate ("Send At") of the NMEA signal. (Two seconds is adequate.)

{__} Back under "Configuration ~ RTCM" you will find "Stale Time." This is the duration that the GPS receiver will tolerate before giving up on receiving a RTCM signal with which to correct fixes. In GPD mode, data presentation and collection will stop if no RTCM message is received during this time. (In GPS/GPD mode,

---

[14] RTCM stands for Radio Technical Commission for Maritime Services. Their standard message format is sometimes called SC-104. The latest standard is Version 2.2 published in January of 1998.

[15] The standard for interfacing marine electronic devices. NMEA 0183 stands for National Marine Electronics Association standard released in March of 1983.

after the stale time has elapsed, the receiver will continue to calculate fixes, but they will not be corrected.)

{__} Observe the "Msg Count" and "Msg Gaps" indicators on this same screen. As you watch, you should see the message count increase by at least several per minute. The number of messages received as time passes is a good indication that you are receiving RTCM data from the radio. If this number does not increase, or resets to zero frequently, you probably are not getting satisfactory information from the radio. The problem could be in any number of places. Among them:

- the base station not transmitting,
- your RDGPS radio not receiving,
- bad cable connections, or
- communication parameters set wrong.

If things don't seem to be working, recheck your setup. If this doesn't work, ask your instructor.

{__} Check that your GPS receiver is still computing fixes. Look at the satellite tracking screen (under "GPS Status") and also be certain that the "Position" screen does not indicate "OLD."

{__} Assuming that everything is in order, collect 180 fixes in a file.

{__} Change the RTCM mode back to "Autonomous" and collect another file of about 20 fixes.

{__} Change the RTCM mode back to its default: "GPS/GPD."

{__} Change the protocol for the port you were using back to "XMDM" and the communication parameters back to those necessary to communicate with your PC.

{__} Back at your lab or office, transfer the three files you took to a PC. Examine them. The first and third files should show considerable variation, while the second file should show a tight group of points.

The Geo3 can also do real-time corrections. The process bears resemblance to that for the GeoExplorers. Differences include the way the interface with the cable from the corrections receiver is set up (there is an attachment that goes on the back of the Geo3) and where you find the various options to set up (under COMMS and Other). By this time, if you have been working with the Geo3, you have a pretty good feel for the philosophy behind it and the kinds of actions you have to take to get it to do what you want Using it in real-time mode will not

be a snap, but you should be able to do PROJECT 7I above without too much difficulty.

8
The Present and the Future

IN WHICH we examine several facets of GPS and GISthat are of current and future interest.

There was of course no way of knowing whether you were beingwatched at any given moment. How often, or on what system, theThought Police plugged in on any individual wire was guesswork. Itwas even conceivable that they watched everybody all the time. Butat any rate they could plug in your wire whenever they wanted to.You had to live—did live, from habit that became instinct—in theassumption that every sound you made was overheard, and, exceptin darkness, every movement scrutinized.
    —From the novel *1984* by George Orwell, published in 1949

On the Horizon: Trends

Some time ago, in a GPS trade publication, I read something to the effect that GPS receivers are becoming so integrated with other equipment that GPS itself is becoming virtually invisible. "Oh, great!," I thought. "Just when I've spent all this time and effort learning about it." You may have a similar reaction.

Upon reflection, I realized that the observation, while true for many uses of GPS, probably will not apply to GIS applications. Most users of GPS make immediate use of the satellite signals and do not record them for future processing. The use GIS professionals make of GPS is for the development of data sets, whose quality must be high and which will endure for months, years, or even decades. But it is certainly useful to look at the

trends in GPS use across the board, to more fully understand this amazing phenomenon. The following seem to me to be fairly safe predictions:

• The US NAVSTAR GPS will be modernized.
• There will be competition for the radio spectrum frequencies that GPS uses; if the spectrum is shared, there is the danger that the quality and reliability of GPS signals could be affected.
• Privacy for the average person in the developed world who uses wireless technology will be reduced.
• Accuracy will increase, both gradually and by significant steps. The time required to obtain a fix of a given accuracy will decrease.
• "Precision Farming" will play an increasingly important part in maintaining and enhancing the world's food supply.
• New equipment configurations for database building, database maintenance, and navigation will be developed as technologies merge.
• New satellite navigation systems will emerge, perhaps complementing NAVSTAR, perhaps competing with it.
• GPS will be combined with other systems to provide positional information in places of poor or limited GPS reception.
• "Monumentation"—the activity of providing markers on the Earth to indicate exact geographic location for reference by those who need such information—will increase and change radically in approach.
• Air navigation will be radically transformed.
• Ground vehicle navigation will result in more efficient use of resources.
• Reliability will increase dramatically for some applications.
• GPS signals for some applications will originate from pseudo-satellites on the ground.
• Civilian and military sectors will increase cooperation, the civilian side of GPS becoming relatively more and more important.
• GPS will be the principal mechanism for distribution of accurate information about time. It is feared that GPS time will become so ubiquitous that the expertise for the building of atomic clocks will disappear, as the demand for those shrinks to only a few a year.

- Emphasis will shift from using GPS to provide information to humans who control processes and artifacts, to direct control of those processes and artifacts by GPS.
- More applications of GPS will emerge; those in use will become more extensive.

A brief discussion of some of these trends follows.

NAVSTAR GPS Modernization

You might think of GPS as a modern phenomenon, but there have been GPS satellites in orbit since 1978. The oldest currently operational satellites in orbit in 2001 were launched in 1989 and are being phased out. During 2000 some 16 satellites were only one component away from failing in a way that would make them unusable. The U.S. Congress, known more for its political intrigues and infighting rather than its concern for the citizenry, was debating, in 2000, the issue of whether to adequately modernize NAVSTAR. Probably it will happen, not because of any major concern for the quality of geographic data (the Bush administration has proposed a cut of 22% across the board in the U.S. Geological Survey's budget), but because GPS is pretty much a military necessity.

The (a) uncertainty of whether the United States was going to guarantee sufficient civilian control over NAVSTAR to provide a reliable civilian signal, and (b) the questions of modernization concerned (irked) those in other countries—particularly Europe, where a move is underway to build a European GPS called Galileo. The executive branch of the U.S. government, under President Clinton, did take a large step toward giving the world a satisfactory GPS by removing selective availability (SA) in May of 2000.

What's in the offing, if all goes well, is a $1 billion-plus modernization program that is badly needed if GPS is to serve the coming two or three decades as well as it has served the last one. For civilian use of GPS, the modernization program will look something like this:

2000: Selective Availability removed, never to return. You can check this one off.

2003–2006: Satellites launched during this time (Block IIR) will broadcast a second civilian signal (on a frequency called L2) with the C/A code or an improved, compatible substitute.

2005–2010: Satellites launched during this time (Block IIF) will broadcast a third civilian signal (frequency L5), whose structure is yet to be determined.

2010-future: GPS III satellites. More power plus other enhancements conceived of in the next decade.

In May 2000 there was a startling increase in accuracy—by a factor of 10—for civilian users, when selective availability was eliminated. Of course, this increase in accuracy is for unconnected fixes—and most of us who use GPS for GIS are only interested in corrected data for database purposes. But for database maintenance, which sometimes means refinding features, which is fundamentally a navigation problem, having the new level of accuracy may mean not having to deal with the problems and extra equipment required when using real-time differential correction. That is no small advantage.

The second civil signal is a big, big deal. It will be at 1227.6 MHz, called GPS L2. The civil signal on L1 is at 1575.42 MHz. The speed of light and radio waves in a vacuum is the well-known constant "c." But when electromagnetic radiation travels through substances (e.g., water, glass, air) the speed changes—and the amount of change is dependent on the frequency. Having two signals of different frequencies to work with allows a properly programmed GPS receiver to "calculate out" most of the error caused by the atmosphere. And, now that SA is gone, the atmosphere (the ionosphere, actually) causes most of the error that there is. If the average error from all sources, considering only one frequency, is, say, 11.5 meters it could be reduced to about 4.7 meters—quite an improvement!

The third civil signal, to be broadcast at 1176.45 MHz (GPS L5) was also announced by Vice President Gore in 1998. It has a somewhat different purpose. The signal at L2 will provide considerably increased accuracy, but is subject to interference from certain radar transmitters. L5 does not have this problem. The signal at this frequency will be designed for safety-of-life services.

But GPS modernization will probably proceed in fits and starts—dependent as it is on U.S. political institutions. For example, Congress in October failed to fund the National DGPS system, even though the transmitters needed to operate it were going to be

essentially free. The system would have provided dual coverage, high precision augmentation of the GPS signal for aviation and maritime applications across the United States.

Better Accuracy

In addition to the gradual increases in accuracy that will be brought about by improved equipment and processing methods, several other factors will considerably improve what we may expect of GPS in the future. As you know, military receivers are able to be more precise than civilian ones for a variety of reasons. One is that they receive on two frequencies. Comparison of the two signals allows a better estimation of the error caused by the ionosphere. Good news: As I mentioned previously, on the horizon —beginning in 2003—is a second civilian signal. Actually, what will happen is that, on satellites launched then and after, the C/A code will be added to the existing second military signal (called L2). Having two frequencies will provide receivers with the ability to immediately compensate for one of the larger sources of error: ionospheric delay. Then, perhaps as early as 2005, new satellites will broadcast an additional signal (named L5), dedicated to civilian use, on 1176.45 MHz. The signal may be four times stronger than the existing civilian signal (L1); L5 will be more resistant to interference. While the primary function for the L5 signal is "safety of life" for aircraft navigation, it will provide a robust additional signal for all users.

By having L1, L2, and L5 signals the stand-alone (nondifferential) real-time GPS user will have:

- signal redundancy
- better position accuracy
- improved signal availability
- warning when the GPS signal might become unhealthy (called signal integrity)
- improved resistance to interference from other radio signals
- fewer or no breaks in service

Differential GPS will improve as well over the years, but not as dramatically, And no one has suggested yet that, to use GPS for GIS you can do without it.

The wide availability of DGPS signals will increase and improve, as will the types of origins of such signals. Between the

Coast Guard Beacon network, commercial firms offering FM subcarrier signals, and the DGPS signals that come via communication satellite, DGPS is pretty much available in the United States. For really precise work, DGPS is required anyway.

Competition for the Radio Spectrum

If your campus is like mine, every third pedestrian student has a cell phone glued to his or her ear. If your town is like mine you would be wise as you drive to keep a wary eye out for vehicles operated by people steering with one hand and chatting wirelessly, perhaps with their children or brokers. To find a place to channel all that telephone traffic, the people who make money selling the service have to find "bandwidth" somewhere. Guess what one of their targets is. Right. The GPS frequencies.

Toward the end of the 1990s, application was made by the mobile satellite system (MSS) industry to share the L1 band for downlinks of voice and data. The application almost succeeded, despite the dangers that such frequency sharing might have caused possible interference with the civil GPS signal. It has apparently been turned back by the World Radio Conference.

The L2 frequency band also has been eyed—by those designing wind profiler radar and space-based radar. These applications were deferred by the international body responsible for handing out the frequencies, and probably the spectrum is safe for the time being, but it was a close thing. (Maybe it helps to have the military on our side?)

Another threat to interference-free GPS signals may come from ultra wide-band (UWB) electronic devices that may undermine GPS reliability. These devices may be used for the precise measurement of distances, for obtaining images of objects buried underground, or present within buildings; their bandwidths exceed one gigahertz, but they use the spectrum in very specific ways that may or may not cause interference with other signals. The argument is that they will coexist with GPS because "they create no more radio interference than a hair drier" was attacked by Charles Trimble, longtime and well-noted GPS expert who identified five crucial differences between a UWB device and a hair drier:

- A hair drier is not usually on all the time
- It's rarely portable
- It has no antenna

- It is not connected in networks
- You can't convert a hair drier into a GPS jamming device

Location Based Services—Economic Boon? Invasion of Privacy?

As this book goes to press the dot-com bubble has burst but there is a new make-a-billion scheme on the horizon. It is called Location Based Services (LBS). The bet is that your location at given times makes you eligible for getting services, or being made aware of services, that you will be willing to pay for, directly or indirectly. Look at some examples:

1. Your car quits (or hits a tree) in some remote area. Almost instantly people you would like to know about your misfortune can be made aware of it, and of where you are within several feet. This system is already installed on some, mostly luxury, automobiles. It utilizes radio transmission of your position as determined by GPS.

2. You are navigating city streets toward a destination, according to aural instructions and a map display. Your in-car unit knows where you are by GPS and perhaps some additional gadgetry (like wheel counters and/or an inertial measurement system) that works when you go through tunnels and urban canyons. Except for the GPS, this system requires no inputs from outside. The GIS information comes from a CD-ROM in the unit. But this capability could be combined with a LBS that warns of traffic congestion on your intended route, and provides information about an alternative.

As of October 2001 in the United States, your cell phone is required to be able to make your location known within 125 meters two-thirds of the time. So if you dial 911—whether you are outdoors, in a car, or inside a building—emergency personnel can find you.

3. Your cell phone has been in standby mode—thereby transmitting its presence to a nearby cell tower. You suddenly hunger for a hamburger. A few presses of some buttons and a map is displayed on the screen of your phone, showing the locations of nearby eateries. Your handset is "location aware" so you can access such "location-based content."

4. You are in Japan in one of several hundred cities. You need to see the location of an address and how to get there. You've paid $3 per month for a service that will do the equivalent of Mapquest or MapBlast!, admittedly on a small screen.

5. You are cruising down an interstate highway and a traffic situation develops that causes you to exceed the speed limit by 20 miles per. A week later a bill arrives for $146.50 for speeding—time, date, and place automatically recorded.

I don't think I need to belabor the point: The advantage, when you use wireless technology, is that **"They know where you are."** The disadvantage, and maybe danger when you use wireless technology, is that **"Theyknow where you are."**

Precision Farming

The authors had the amazing and scary experience of flying in a helicopter during a simulated fertilizer spraying run. (As a "fixed wing" pilot I regard any flying condition in which the ground is less than 50 feet away, except when landing or taking off, with extreme trepidation.) The helicopter was equipped with the Trimble Trimflight GPS system that allowed the pilot to fly precisely along a predetermined grid superimposed on an image of the target field, shown to him by a computer display. Further, a set of lights told him if he was left of, right of, or on course. Normally, the navigation involved in spraying a field is accomplished by (1) the pilot remembering approximately where he was on the last pass (in addition to flying the bird and keeping it out of the wires at the end of the field), and (2) some poor fellow on the ground, covered with crud, waving a white flag.

Not only was the spraying operation made safer by Trimflight, it was also made more effective. Earlier, during harvesting, a combine had collected location-specific yield data on the field, showing areas of more and less fertility for the crop. Chemical soil samples were taken, indicating site-specific deficiencies. So when the spraying operation took place, the amount of product could be metered depending on the position of the aircraft. The results: more stuff in the right spots, less pollution, less expense.

Less dramatically, the same sort of application of pesticide or fertilizer can be done by ground-based equipment; that has the advantage of not having the **"LOW FUEL"** light flashing, as we did on our flight.

All in all, precision agriculture is one of, if not the, most significant GPS application, whether done with aircraft or, more usually, with ground-based equipment.

Other Countries, Other Systems

Since the United States has been very proprietary with the more accurate aspects of the NAVSTAR GPS, people in other parts of the world look with concern at hanging their navigation, timing, and position recording capability on a system over which they have no control. For some time now, the European Union has been planning to develop its own Global Navigation Satellite System (GNSS) to be called Galileo. Why would a second (actually, a third, considering GLONASS) GPS be necessary, or even useful? Besides the issue that other countries do not want to depend on the United States and its fickle political institutions for quality position information in the coming decades, NAVSTAR GPS has a number of other short-comings that make development of another system useful.

Because it will be designed from the ground up as a utility, Galileo may:

- allow more accuracy
- be more reliable
- admit to the user immediately when it fails
- be more secure

If the Europeans build Galileo, a major question will be whether it will be "interoperable" with NAVSTAR or will compete with it. If the two systems work together we could easily see a 50-plus satellite constellation that would provide marvelous availability, accuracy, redundancy, and integrity.

As this book is going to press, a number of events suggest that the direction of the future of GPS (or to use the more general term GNSS [Global Navigation Satellite System—they still haven't got "timing" in the name]) is not as predictable as the past was. In December 2000 the Council of Transport Minister of the European Union met to determine the direction of the Galileo System—indeed, to decide its fate. But the December 2000 meeting did not make a final go/no go decision on Galileo.

Of course, there is already another GPS system up and running: GLONASS has had almost the same number of operating satellites as NAVSTAR, and has been around about as long. (The first GLONASS satellite was launched in October 1982.) But the Russian program has suffered greatly in the past five years due to financial difficulties. During the year 2000 the system fell to only

eight operating and healthy satellites. Three more were launched in October of 2000, so the system is moving back toward operability.

China surprised everybody when it launched a test navigation satellite named Beidou—their name for the Big Dipper. There is talk of a partnership with the Russians. Japan, on the other hand, seems content to make use of the GNSS that other countries are planning or maintaining. The Japanese are installing one and half million car navigation systems a year.

Japan's interest has been sharpened by the number of large earthquakes and other disasters they have had. Can GPS aid in predicting earthquakes? They certainly think so. While they are not intending to add to the number of GNSSs, they do have plans for use of satellite positioning systems in aircraft and automotive transportation: the Multifunction Transport Satellite Service (MTSAT), which is a geostationary satellite overlay service.

Augmentation Systems

The Europeans also plan on their own system for aircraft navigation, based on satellites parked over the Equator: the European Geostationary Navigation Overlay Service (EGNOS). It will be operational in the near future. A U.S. augmentation system (WAAS) is discussed later in this chapter.

Faster Fixes

While GPS at present can provide surveyors with the centimeter-level accuracy they require, the length of time they need to "occupy" a location is usually prohibitive for routine land surveying activity. (Employees of surveying firms sometimes comment that the term GPS means "Get Paid for Sitting.") The kind of accuracy surveyors need requires that the receiver stay in constant touch with the satellites, so that they may actually count the number of wave cycles of the radio signal between the antennas. This is termed "carrier-based" position finding, as differentiated from the GPS work (code-based) that you have studied. In areas or conditions where the receiver may "lose lock" on the satellite, the process can be not only long, but frustrating. Better equipment and the availability of carrier phase DGPS signals will begin to make GPS viable for many more surveying applications.

GPS manufacturers are aware that the speed with which a receiver can acquire enough satellites to know where it is, bears on marketing as well as position finding. If they do well in this arena they advertise their "time to first fix."

GPS Combined with Other Systems

It has been commented that GPS bears a resemblance to sanitation plumbing of a hundred years ago: basically an outdoor activity. But often we want to know where we are when we don't have the luxury of a line-of-sight relationship with four or more satellites. In tunnels or mines or caves, for some examples—even in deep valleys or on urban streets—GPS operates at a disadvantage. One way to locate your position, assuming you knew it at some time in the past, is an Inertial Navigation System (INS). An "INS" is a mechanical apparatus whose heart is a set of spinning gyroscopes; it can detect very small changes in its position and report these to an operator. Marine navigators can place position data into such systems while still in harbor, sail for three months, and return to the point of origin, with the "INS" indicating the original settings within a hundred yards or so. Certainly it is possible for a vehicle that is mapping a road system to have an INS onboard to see it through tunnels, or valleys between skyscrapers.

The Ohio State University Center for Mapping has developed a van for delineating highways that combines a number of position locating techniques and systems with photographic or videographic information, showing pavement condition, signs, intersections, and the like. The information can be installed in a GIS. Later, a point on an interactive computer map can be selected and the user can "drive" along the road, seeing the features.

Monuments Will be Different, and in Different Places

Things are changing at the National Geodetic Survey agency office — more in the past 10 years than in the preceding two centuries (well, almost; Thomas Jefferson set up the Survey in 1807). Monuments used to be on the tops of mountains, since line of sight was vital to the surveying profession. Line of sight is still vital, and still in the upward direction, but toward the satellites. And instead of static monuments we can expect radio-dynamic ones, that announce where they are. Further, the physical monuments will be

more accessible and more closely spaced—and a lot more accurate, having been "surveyed-in" with GPS techniques.

The charted positions of many places have been changed based on GPS information. Numerous islands have been moved from their originally charted positions. The coordinates of the city of Hannover, in Germany, shifted a couple hundred meters to the south as worldwide systems replaced national ones.

Air Navigation Will Be Radically Transformed

The U.S. Federal Aviation Administration awarded a contract for the Wide Area Augmentation System (WAAS) for $475 million, whose primary basis is GPS. Should this come to pass, ground-based navigation stations and towers will become obsolete, as may ground-based radar units. Today, to keep track of a flight, a flight controller's radar sends a pulse which strikes the airplane and triggers a "transponding" pulse from a radio carried in the aircraft. This gives the controllers on the ground the 2-D information they need to tell the pilot where to fly to avoid other aircraft. But the altitude information has to come from the airplane's own altimeter, whose readings are based on barometric pressure. With GPS, the airplane's electronics will simply know where it is, in all three dimensions, and that information will be sent directly to the controller.

That is, if there is a controller. It may be that an intelligent, computer-and GPS-based system will provide navigation and collision-avoidance information directly to the pilot.

That is, if there is a pilot. Since the GPS-based system could certainly control the aircraft…no, no, I take this too far. Surely there will always be pilots.

Due to some unfortunate decisions, cost overruns, and other factors, the WAAS is not developing as quickly as was expected.

One concept that is being discussed is doing away with many of the airways. At present, aircraft operating under instrument flight rules (IFR, where pilots whose planes are in the clouds avoid hitting the ground by reference to charts and instruments, and avoid hitting other planes by being told where those planes are by a radar controller on the ground) follow highways in the sky. And just like highways on the ground, they do not usually lead directly from the trip's origin to its desired destination. One reason for the detours is collision avoidance. A second is that navigating the airplane is based on having to go through intersections (where the

limited-range, ground-based antennas are). The combination of GPS and "real-time GIS," which shows the location of other aircraft, can obviate both of these factors.

If every plane could fly "direct," detouring only when the GPS/GIS system suggested that the current course might result in bent metal, vast amounts of time and resources would be saved.

In addition to navigation en route, GPS systems, augmented by real-time differential techniques, have shown abilities to provide positional information of less than half a meter to landing aircraft.

Marine and Vehicle Navigation Will Be Improved

Something on the order of a million in-car GPS navigation systems are being installed each year. Not only do these systems allow navigation based on the static facts of where the roads go but also on the dynamic facts relating to where the other traffic is. Tokyo will soon benefit from such a system.

In addition to vehicle route guidance, intelligent transportation systems (ITS) will provide other benefits, such as fleet vehicle dispatch and tracking, and emergency notification of police and tow trucks. Before you cheer too loudly, however, realize that without proper safeguards, Big Brother may know where you are, where you are going, and how fast. Already, automated systems exist in the Unites States that scan license plates of speeding cars and send a ticket to the owner.

System Integrity and Reliability—Great Improvements

While you might think that the maximum safeguards would be provided for a system designed to aid a warrior with a mortar or a nuclear-tipped ICBM, the fact is that GPS position data can suddenly disappear for periods of a few seconds to a few minutes. That state of affairs is not going to be allowed for some important civilian applications. You will understand the need for reliability immediately if you imagine yourself as a passenger in a landing commercial aircraft. The plane is 50 feet above a runway in a blinding snowstorm. That's no time for GPS to take a breather.

It is going to be possible for ships to navigate in shallow water by knowing their vertical height and having an integrated survey of the bottom of the water body. On-the-fly marine navigation

requires 3-D GPS decimeter (that's 10 centimeter or 4 inch) accuracy. Again, everything has to work right and keep working.

GPS will be vital to all sorts of civilian and commercial endeavors, so the systems built around it simply must be highly accurate and reliable.

Civilian and Military Interests WillContinue to Cooperate

Presidential Decision Directive 63, issued 29 March 1996 declared "A permanent interagency GPS Executive Board, jointly chaired by the Departments of Defense and Transportation, will manage GPS and U.S. Government augmentations."

In September 2000 the Civil GPS Service Interface Committee announced that DoD and DoT agreed to seek greater involvement from civilian federal agencies in the day-to-day management of GPS. Civil representation is to be sought throughout all stages of the DoD acquisition, requirements development, and planning, programming, and developing process.

Once the civilians and the military agree on a few more issues related to GPS accuracy, coverage, and integrity, GPS will be the primary U.S. government radio-navigation system well into the next century. The satellites which will be launched to provide GPS information in 2015 and beyond are already being designed. Swords are being beaten into plowshares, but the changes will not come rapidly, for both political and security reasons.

A real breakthrough would be the deployment of a way to jam GPS signals in a given geographic area, thus denying an enemy any use of the civilian GPS signal.

GPS Will Become the Primary Way toDisseminate Time Information

A GPS receiver is one of the most accurate clocks in the world, if it has continual access to the satellites. The forte of a clock in a GPS receiver is short-term accuracy, not long-term consistency. People who really want to know exactly what time it is can set up a base station over a known point and analyze GPS signals for time instead of position. GPS time does differ from UTC time by an integer number of seconds, less than 20 for the near future. There are many applications for which coordinated time is vital.

Examples: making the telephone system, the banking system, and the Internet, on which the World Wide Web is based, run smoothly.

GPS: Information Provider or Controller?

There will be an increasing number of applications in which GPS signals control equipment directly, rather than going through a human "middle-man." In such joint GPS/GIS uses as fertilizer or pesticide application, the automated system may steer the tractor while the farmer rides along simply for reasons of safety. Carving out roadways or laying pavement may be conducted in similar fashion. The Center for Mapping at Ohio State University boasts a system that can put a bulldozer blade in the correct position with an accuracy approaching one centimeter.

Applications: New and Continuing

New applications appear every day, from vital operations such as golf cart tracking and pin ranging, to incidental ones such as aiding farmers in feeding the hungry people of the world by enhanced agricultural techniques. Animals can be tracked by researchers. Polar ice sheets can be monitored. Blind people can be guided. Rescue helicopters can be directed. Solar eclipse tracks and weather information can aid navigating astronomers. Chase cars can follow hot air balloons, even when they can't be seen. And in space: some satellites carry GPS receivers! What better way to report on exactly where they are?

The magazine *GPS World* reports monthly on new applications, and spon-sors an applications contest once a year. And, of course, the World Wide Web has information of interest to those searching for information on GPS.

More Equipment and Software Configurations with GPS and GIS

The direct integration of GPS and portable computers running GIS has been a reality for some time, allowing new facility in navigation and data collection. The company GeoResearch developed GeoLink software which linked GPS input to a microcomputer running GIS software.

As you may recall from the flying tour example of Chapter 7, Trimble Navigation makes a software product called Aspen that

runs on a portable computer. A PCMCIA GPS receiver card (also called Aspen) is inserted into a socket in a laptop, notebook, or "pen" computer and an antenna is attached. When the Aspen software is running it looks a lot like Pathfinder Office with some additional menus for controlling the GPS receiver and recording data.

A sister product, "Direct GPS" integrates GPS signals, RDGPS correction broadcasts, and turns a standard computer into a datalogger and navigator. Direct GPS displays position information, with Arc View providing the software context.

Another configuration gaining in popularity is the use of a handheld touch screen computer, such as the Compaq iPAQ, running ArcPad software from ESRI. Basically, you can download ESRI or other data files and image files to the handheld computer, attach a GPS receiver to it, and go into the field. GPS shows you where you are in the context of the area of interest. Once there, you can collect data, correct data, or perform other database maintenance functions.

If your requirements are more in the navigation line, you may obtain a GPS receiver, software, and map data from DeLorme and hook it to a Personal Digital Assistant (such as a Palm Pilot).

A truly intriguing method of data collection and database maintenance is available from Datria Systems. It combines GPS capability with voice recognition software. In use in several metropolitan areas, it allows a person to collect data by simply speaking into a microphone while walking or driving with the system. The data collector might say, "stop sign down, 4 feet right" and later "broken pavement 20 feet ahead" and this information would be recorded in the unit. Back at the office the synchronized voice data and GPS fixes are uploaded into a PC that turns the voice print into written text and writes and routes job orders to the departments responsible for signage and pavement repair. It is easy to believe that this system lives up to the claim of making such data collection 10 times faster than even "traditional" GPS data collection techniques.

As previously mentioned, ESRI has produced an Arc View extension called the Tracking Analyst that allows real-time tracking of GPS receivers, or "playing back" data taken by such receivers. Basically, the Tracking Analyst allows the user to plot GPS data as it is being acquired, by virtue of radio transmissions, perhaps by communication satellite or cellular telephone, of the GPS data to a location that then relays these data to the Arc View

software. Information from the tracking analyst can be routed to the ESRI Internet Map Server (IMS) to make map data available on the web. Some interesting projects involving wildlife tracking (elephants and elk) are underway using this technology.

Kodak makes a digital camera to which you may attach a Garman GPS receiver. This can create a watermark on the image itself, or become a part of the attribute data in the image file. Probably other camera manufacturers will make such products and interface them with other GPS units.

Sometimes you want the GPS position of an object that is some distance away and not convenient to get to or, perhaps, inaccessible. Maybe you want the x, y, and z of Thomas Jefferson's nose at Mount Rushmore, in the Black Hills of South Dakota, without risking life and limb to record the data. Some GPS receivers may be outfitted with a LASER range finder that can report the distance and direction of an object at which it is aimed. An accuracy of half a foot over a distance of 2,000 feet can be obtained.

There's a gadget that determines the character of light that goes through the leaf of a plant—thus revealing information about the chemical composition of that leaf. Hooked to a GPS receiver it allows the location of the plant to automatically become part of the data file.

Want a small GPS receiver? Furuno USA makes one that is 28 mm×21 mm×10 mm and weighs 18 grams. That's a little more than an inch long by a little less than an inch wide by less than half an inch thick—and four hundredths of a pound.

The Future—Who Knows?

If you are using this text after 2002 you may well know more about what is happening then than is printed here. And what is said here may be wrong or completely out-of-date. That's the way of accelerating technologies like GPS.

Appendix A
Source of Additional Information About

Some places to look for additional general information about GPSand its applications:

GPS World, monthly journal, Advanstar Communications, www.gpsworld.com

Integrating GIS and the Global Positioning System, book, Karen Steed-Terry, ESRI Press, www.esri.com

GPS for Land Surveyors, second edition, book, Jan Van Sickle, Ann Arbor Press, www.sleepingbearpress.com

Interagency GPS Executive Board (IGEB), www.igeb.gov

If you are interested in more Internet sites you can go to a web search engine (e.g., www.google.com) and type Global Positioning System into the search field. That will give you the possibility of about 400,000 pages to look at, which ought to use up the better part of an evening.

For technical information on GPS orbits, timing, satellite condition, andsoon:

U.S. Coast Guard Navigation Information Service, www.navcen.uscg.mil

Canadian Space Geodesy Forum, gauss.gge.unb.ca

Geodetic Survey Division, Geomatics Canada, Natural Resources Canada, www.geod.nrcan.ca

U.S. Airforce Holoman GPS Website, gpstest.46tg.af.mil/coe/bbs

U.S. National Geodetic Survey (NGS), www.ngs.noaa.gov/GPS/GPS.html

Scripts Orbit and Permanent Array Center (SOPAC), csrc.ucsd.edu

U.S. Naval Observatory (USNO), ttycho.usno.navy.mil/gps.html

National Imagery and Mapping Agency, http://164.214.2.59/GandG/sathtml

For information about GLONASS:

www.rssi.ru/SFCSIC/english.html

For information about Galileo:

Galileo's World, quarterly magazine, Advanstar Communications,

www.galileosworld.com

Galileo Program Office, www.galileo-pgm.org

Glossary of GPS Related Terms:

www.gpsworld.com/resources/glossary.htm

Appendix B
Form For Exercise, Lab Practical, and Exam
using data sets that are on the CD-ROM

For the assigned folders or files please provide the following information:

File of Folder designation(s) _____ Receiver Type: _____

File Date (dd/mm/yy): _____ Duration of file(s) _____

Number of fixes _____

Corrected file? Yes (__) No (__) SA was? On (__) Off (__)

Time of first fix: _____ GMT _____

Local Time of last fix: _____ Local

General location of data collection _____

Specific site of interest, if any: _____

Positions of first fix and last fix:

(WGS84: latitude, longitude, altitude [meters]) _____, _____, _____

(WGS84: latitude, longitude, altitude [meters]) _____, _____, _____

The receiver antenna was: STATIONARY (__) MOVING (__)

If the antenna was STATIONARY, give these statistics:

Average northing, easting, altitude: _____, _____, _____

Standard deviations of the averages: _____, _____, _____

If MOVING: Largest distance between fixes (specify units): _____

Probable method of antenna conveyance: _____

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